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PROCEEDINGS OF: INDUSTRY/SAMSO CONFERENCE AND WORKSHOP ON MISSI--ETC(U)
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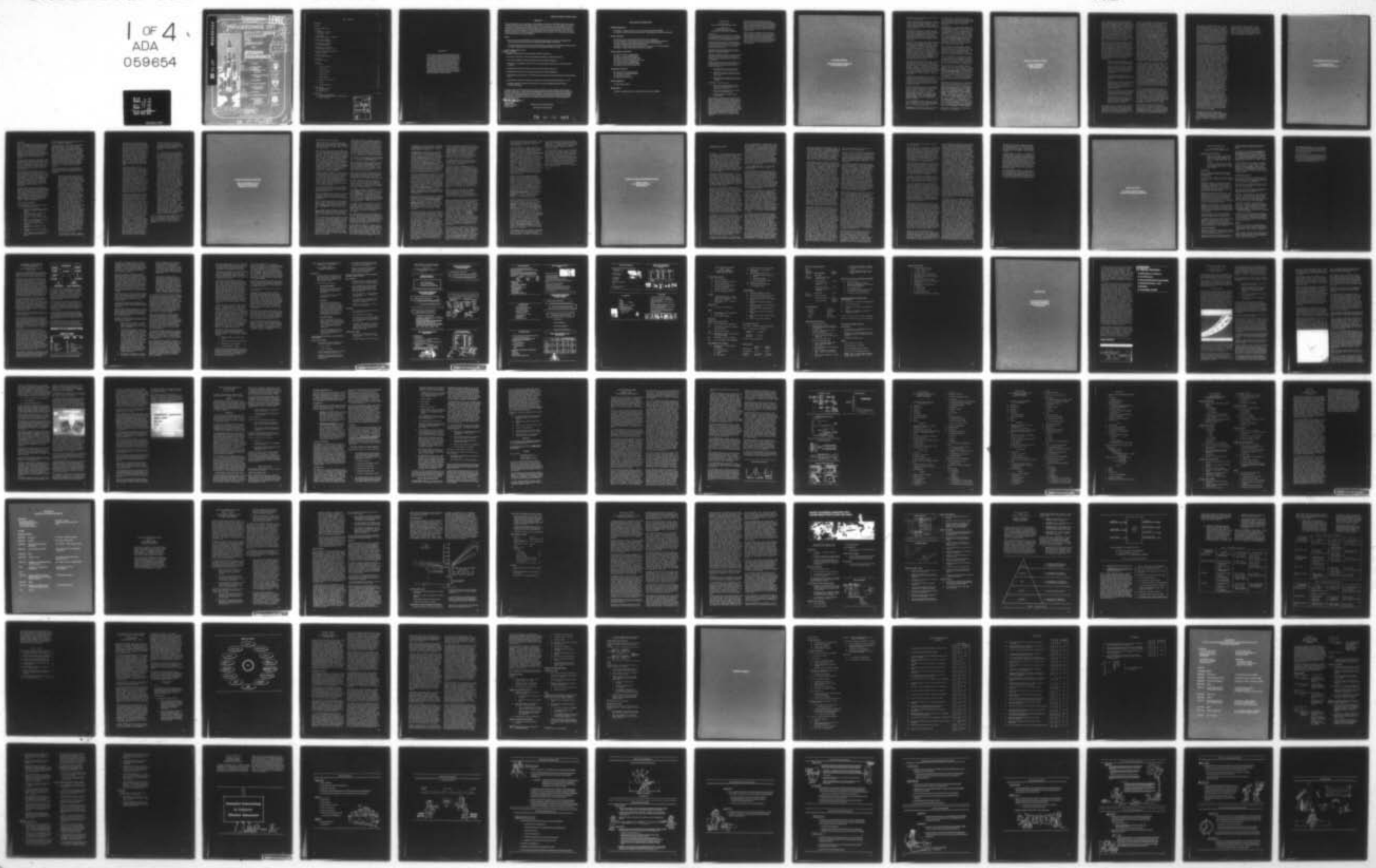

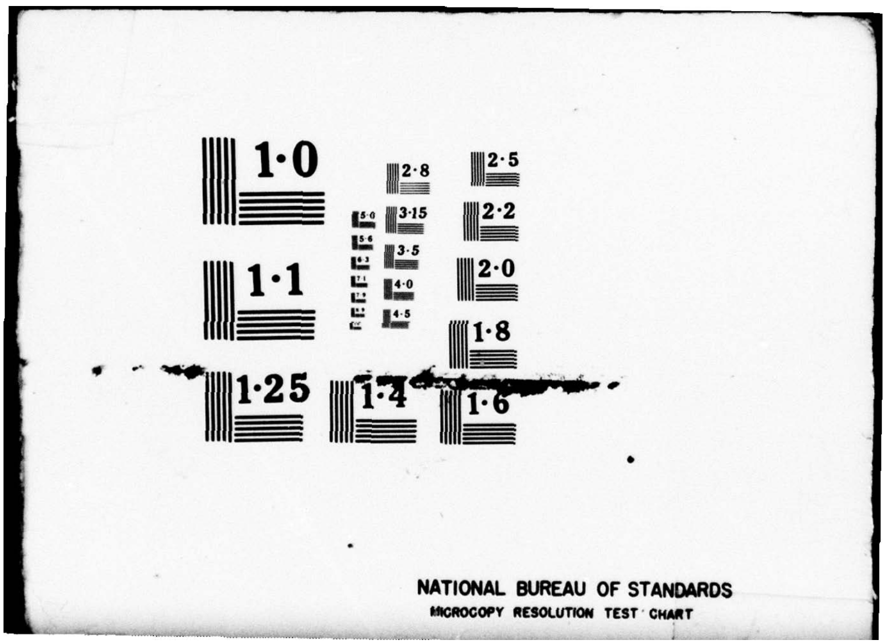
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PROCEEDINGS OF: INDUSTRY/SAMSO CONFERENCE AND WORKSHOP on MISSION ASSURANCE

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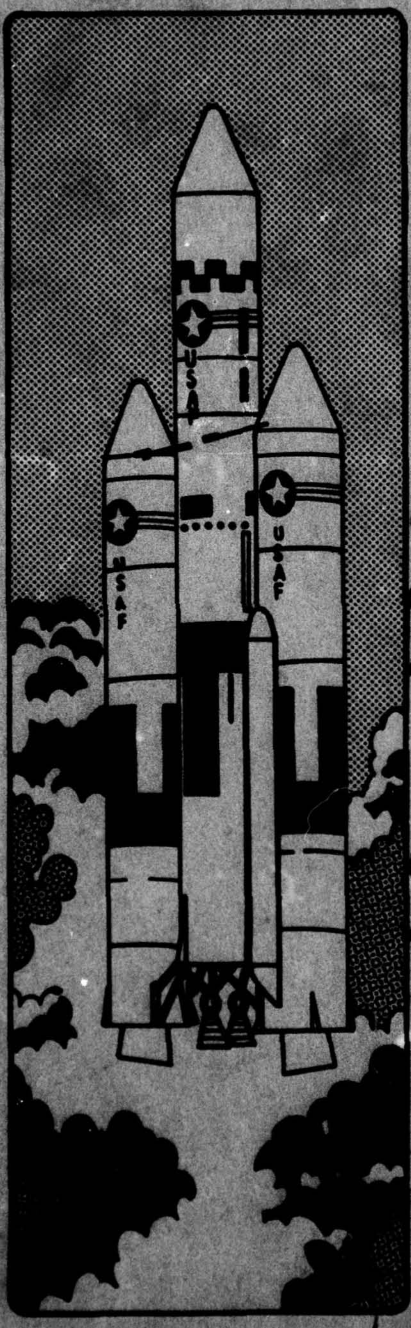

(9) Technical rept.

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- PIECE PARTS
- SUBCONTRACTOR CONTROL
- MICROELECTRONICS/ HYBRIDS
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- MANUFACTURING
- CONTRACTUAL INCENTIVES
- TESTING
- PROGRAM REVIEWS
- MOTIVATION/ TRAINING/ EXPERIENCE SHARING

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BACKGROUND

During mid 1977 Lt. General Thomas W. Morgan, Commander of the Air Force Space and Missiles Organization, SAMSO, met with key executives of the space industry to discuss fundamental issues that would enhance spacecraft mission success. These leaders collectively identified a wide range of key elements that were critical to successful space missions. The participants and a summary overview of the Executive Sessions are included in Appendix B of these proceedings. Three industry associations (NSIA, AIA, and ADPA) accepted the challenge to explore these issues in greater detail in a conference/workshop environment to examine key elements and factors critical to space mission success. The intent of the sessions was to identify tools, techniques and methods in acquisition and procurement to minimize and control risk through improved management and practical implemention of all actions affecting the achievement of Mission Assurance.

ABSTRACT

These proceedings tell only a small part of the tremendous effort behind the SAMSO/Industry Conference on Mission Assurance, 25-27 April 1978, as many months of preparation, study and research were required by speakers, co-chairmen and workshop participants. This volume contains the proceedings of a unique conference that looked at ways to enhance mission success from a "Systems Approach" rather than from a specialized or parochial standpoint. The formal speeches contained herein set the stage for the panel and workshop sessions by providing management overview and policy perspective. The main points of the panel and workshop sessions are summarized below:

Panels

- The piece parts panel presented an overview of the various aspects of piece parts management for Mission Assurance from the perspective of SAMSO, NASA, DESC, and Industry.
- The Design Panel discussed, from an executive viewpoint, the importance of establishing mission success as a primary design goal, and techniques for assuring implementation of this goal.

Nine Workshops held to discuss:
* Partial Contents:

- Design considerations and responsibilities for Mission Assurance;
- The role of contractual incentives in Management Motivation for Mission Assurance;
- The role of Management and Program Review Process in Mission Assurance;
- Techniques for management and control of the development and application of systems computer software;
- Subcontractor/supplier interface and control to achieve Mission Assurance;
- Development and Control of microelectronics/hybrids for space application;
- Identification and examination of manufacturing and assurance techniques required to minimize mission risk;
- Optimization of testing of components, subsystems, and systems for Mission Assurance; and
- Industry's approach to personnel motivation and training and SAMSO/Aerospace/Industry experience sharing.

The papers prepared by the Government and Industry workshop and panel members reflect advanced thinking in many areas. In some instances the positions given may not be compatible with that taken by the same individuals while serving in their official capacity. All of the panel members were encouraged to divorce their "workshop thinking" from the constraints imposed by existing directives and practices. This approach was considered essential to the effectiveness of the conference. The papers should be treated in this context.

M.A. McGowan
M.A. McGowan
SAMSO/PMGQ
SAMSO Conference
Project Officer

Approved for Public Release

Unlimited Distribution

CONFERENCE ORGANIZATION

Conference Moderators

Col. William L. Bagwell, Director of Launch Vehicles Procurement, SAMSO
Mr. Gerald E. Lutz, Quality Assurance Director, Fairchild Space and Electronics Company

Program Committee

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Mr. M.A. McGowan, Chief, Quality Assurance Division, SAMSO/PMGQ (Chairman)
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Mr. Allan J. Boardman, The Aerospace Corporation
Mr. Edwin S. Shecter, Manager Product Assurance, Govt. Sys. Div., RCA Corporation
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Mr. Paul L. Burdeno, SAMSO/PMGQ
Maj. Robert S. Dalrymple, SAMSO/PME
Mr. Peter H. Dirnbach, Rockwell International
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Courtesy of Hughes Aircraft Co., Rockwell International, and SAMSO

INTRODUCTION

Col. William L. Bagwell
Director of Launch Vehicles Procurement/SAMSO

Gerald E. Lutz
Director of Quality Assurance
Fairchild Space and Electronics Company
(Chairman, Air Force Liaison Panel – NSIA QRAC)

Good Morning - - -

On behalf of SAMSO and Industry (NSIA, AIA, and ADPA), we want to welcome you to what might well be an historic occasion, an exploration and open exchange of technical and management information intended to improve SAMSO Mission Assurance.

This is the first conference known, at least to those who have worked in the conference framework, that has crossed discipline lines in a common interest and objective – very refreshing after years of trying various means – Product Assurance, Mission Success, Systems Effectiveness, etc.

A real keypoint is the fact that Industry and Governmental agencies have found a common base to perform a dialogue for a common goal – MISSION ASSURANCE.

A great deal of credit must go to the 50 or so committee members from Industry, SAMSO and Aerospace for their dedication in selecting not only the subject matter, but by designating and allowing top people in the field to present their points of view in the subject areas.

SAMSO and Aerospace have made their own self-analysis, now it is Industry's opportunity to review and critique SAMSO/Aerospace practices in a very positive professional manner. Our goals within each session are:

- Identification of deterrents and counter-productive practices having an effect on mission attainment.
- Development of cost effective approaches to/or better utilization of information and resources to enhance mission success.
- Determination of new or better application of existing techniques providing a forcing function to mission risk minimization.

Overall objectives of the conference are to:

- Simulate exchange of ideas between Industry and Government on management/technical/acquisition support aspects of mission assurance.
- Provide a forum through which the total community can impact and address problem areas.
- Provide a continuance to the SAMSO/Industry Executive Sessions.

Please be aware that for these sessions, the Government is to be treated as a partner instead of a customer – tell each other your concerns. It is incumbent upon Industry to define counterproductive and cost/risk drivers through analysis to assure that dollars spent is in best interest of both Government and contractor relative to achievement of a complete successful mission. There is an outgoing challenge to Industry to make both good and bad experience sharing happen so that all parties benefit. If we are to be successful, a free and open exchange is essential. We encourage each of you to feel free to express your thoughts throughout the workshops. Workshop leaders will present aspects of their subject matter for further discussion. These, as well as other recommendations from each of you, are the backbone of the workshop.

Mission Assurance is indeed top Management's business, especially if the lack of it prevails and is reflected in mission failures. Failures impact follow-on contracts and consideration for other future business. Management motivation can be achieved effectively through contractual performance incentives properly timed within a contract. In a failure mode, schedule and other management/program milestones are secondary to achieving a successful mission.

Where to from here? A real question – should we continue Executive Sessions and follow-on conferences or workshops in particular interest areas? The answer to this lies within the workshop session and results achieved. An aggressive attitude by management and all disciplines to make "success happen" is required. Personally, I would like to entertain an Executive Session in six months to review any impact due to changes implemented as a result of either the earlier Executive or these Conference sessions.

WELCOME ADDRESS

Major General Howard E. McCormick
Vice Commander, SAMSO

Good moring, ladies and gentlemen, and thank you Mr. Lutz for your remarks.

The goals and objectives established for this conference are both vital and challenging. On behalf of General Morgan and SAMSO, I want to thank industry for accepting the challenge and establishing this forum to examine the important aspects of mission assurance.

General Morgan also sends his personal greetings and welcome. Although his retirement this week precludes his attendance, he sends his best wishes for a successful and productive conference. I should add that General Henry, who will replace General Morgan, has asked me to express his support for the objectives of the conference and his best wishes.

During the joint meetings last summer with industry executives, many of whom are here today, General Morgan expressed the SAMSO position that: while the record of our spacecraft and missile programs is very good, the impact of a small number of failures can be devastating. This impact goes beyond the initial loss of operational capability and the loss of resources. It also seriously impedes our ability to obtain congressional support for future budget allocations. Management at all levels has to recognize that, for space applications, we must strive to achieve perfection. This may be initially costly, but the alternative is even more costly in the long run.

This conference in itself is very unique. In many conferences you find a very narrow range of subject matter, and a conference of experts talking to other experts on the same subject -- preaching to the choir if you will. Seldom do we see the broad viewpoint presented in a manner that cuts across functional lines permitting us to visualize how one area or function affects and interacts with another. This conference certainly provides for cross pollinization and "bridging the gaps" among functional lines.

To the best of my knowledge, this is the first conference we have held that covers so wide a range of elements which are key factors in mission success. This multi-discipline approach - taking a horizontal cut at the entire range of problems that impinge on mission success - mark this as a milestone conference.

No one realizes more clearly than this assembled group that attaining the quality, reliability and performance levels required for our space and missile systems is a tough job -- one that requires constant attention and vigilance. No single segment of either the contractors' organizations or the government can accomplish these objectives alone. Working as a team, we must identify and adhere to certain fundamentals in the acquisition process.

We on the government side must make sure that we contract properly for reliability and performance. This, of course, must include proper incentives to achieve a reliable design and product.

Contractors must strive for mission assurance from the very beginning by designing systems that eliminate failuers or minimize their impact if they should occur. Constant vigilance must insure that reliability and quality do not degrade during manufacturing and efforts must be sustained through deployment, launch activities and operations.

And we can do it. Our government-contractor team has exhibited many examples of high reliability and exceptional performance. On the missile side we have minuteman III gyro accelerometers which are experiencing a mean time between failures of 150,000 hours - which is over 17 years. During that time the gyro makes some 144 billion revolutions. One of the guidance sets that uses these gyros, plus 15,000 other piece parts, completed 42,400 hours or almost 5 years of continuous running. The original minuteman I first stage motors have a design life of three years, and we just successfully fired one that was cast in June of '63, almost 15 years later.

Our satellite programs have enjoyed a similar record of success. The two satellite Nato III communication system has provided an availability rate of 99.98% since initial launch in April '76. The first of our latest generation weather satellites is presently exceeding its 15 month design life by over 25% and is still going strong.

The first fleet satellite communications system, our most complex and most powerful military communications satellite, was launched in February, and after the smoothest pre and post launch checkout of any of our satellites, was declared fully operational one week before its scheduled date.

We have proven that we can be highly successful, and that's why I am pleased with the positive aspects of the title of this conference -- mission assurance. We must not dwell on the negative aspects, but emphasize success. While we need to identify and eliminate those practices and techniques that are counter productive, we must also refine and continue to improve upon those that are tried and proven. I urge you in your workshops to be candid in your observations and recommendations for improvements in our directives and manuals.

Notwithstanding the many directives, regulations, manuals, military specifications, and all of the other documentation essential to our business, ultimately a successful product is born of good people, properly organized, skillfully managing industry and government resources. In today's environment of tightening resources, of austere budgets and growing concern over environmental impacts, reliability of our products is no longer a luxury. We cannot trust to luck. The systems and components we design, develop and build must work -- the first time. Anything else is unacceptable waste. The tools to assure quality of products are available. The talented people who have made mission success a reality in many of our systems, are well represented in this conference. I am certain that your time will be spent to good purpose in putting tools and talents together for a new level of achievement in mission assurance.

Thank you for this opportunity, and good luck in the outcome of the conference.

INDUSTRY KEYNOTE ADDRESS

Dr. John W. Townsend Jr.
President, Fairchild Space
and Electronics Co.

A little over a year ago, Lt. General Thomas W. Morgan issued what was in effect a challenge to that part of the Aerospace Industry concerned with SAMSO projects and objectives. His challenge was to identify and suggest solutions to general problems that had resulted in or contributed to space mission failures. General Morgan was concerned that an alarming trend was developing. His concern was, and is understandable. SAMSO missions are vital to the security of this Nation. A failure can leave the country uncovered and even invite trouble from the outside. Further, such failures are very expensive. I am sure I do not have to develop this point further with this audience or for that matter with any taxpayer.

During mid 1977, in a series of meetings, General Morgan met with top executives of industry to get their points of view on enhancing mission assurance. I attended one of those meetings and have studied a synopsis of all of the discussions and the many suggestions brought up. I really cannot, and won't, attempt to outline what I consider to be the ultimate solutions--that is really a task that this conference has been called to address. I would, however, like to highlight several particularly interesting areas that were identified in those meetings that strike me as being fruitful for much discussion during this conference. Specifically:

1. Design - Key Words--Overspecification; design for simplicity; redundancy with cross strapping; failure modes analysis.

2. Type of Contract, Incentives, and Subsequent Relationships - Key Words--Fixed Price vs. C.P.F.F; incentives; type of incentive; arms length relationships vs. over involvement on the part of the Government.

3. Parts - Key Words--Where do we get reliable parts in small lots? In process inspection; lot sampling; screening; burn-in.

4. Manufacturing and Quality Assurance - Key Words--Designing in inspectability; configuration control; transition from design to fabrication; continuity of the experienced team; role of quality assurance personnel.

5. Testing - Key Words--Proper environmental specification; testing at lower levels of assembly; realistic simulation of on-orbit operation; analysis of test data.

6. Experience Sharing - Key Words--It's good but how do we do it? Reporting of both flight failure and anomaly information as well as success stories; ALERTS?; coupling with NASA.

Now, I would like to make some personal observations concerning what I consider to be some root problems in our industry at the present phase of the space program and make a recommendation for improvement in a single general area that I feel bears on all aspects of mission assurance.

First of all, the bloom is off of the space rose. Time was when space projects were the most exciting and important efforts in the country. Because of Russian successes and our early failures, the very prestige of the United States was at stake with its own people. The best of everything was marshalled into play. Nothing was too good. The satellite projects and their hardware were treated with "tender loving care" by all concerned. Citizens and their organizations supported and even encouraged greater efforts. In essence, there was <u>identification</u> with the task at all levels of government, industry, and the general public. Contrast that situation to where we are today. From the public standpoint we have been to the Moon and space exploration is now too expensive given our peoples' perception of other needs. Although the situation may be changing now, strong anti-military and anti-technology sentiments have developed that color attitudes and priorities. Government spending is under pressure from all sides. Inflation is a persistent and unsolved problem. In summary on this point, I am simply saying that these external conditions, which have changed so dramatically, have reduced <u>motivation</u> markedly and driven a number of small businesses and even a few larger firms out of aerospace product lines completely. How many times have we heard the comment that the space business is just not predictable or profitable enough given the investment in all types of resources required?

A second root problem is that spacecraft are not production items in the conventional sense. This is the "onesey" or "twosey" problem. There is little ability to operate on a learning curve thus increasing both reliability and efficiency as the serial numbers increase. Further there is no room for mistakes. Space systems must operate with little or no ability to correct errors from the ground. This situation creates unique technical and managerial problems that have to be addressed in special ways, many of them unfortunately based on sad experience. But this can result in quite a "hassle" compared to other lines of industrial endeavor and again <u>motivation</u> can be affected. How many times have we heard comments to the effect that extremely tight specification, large amounts of paper work, onerous terms and conditions, etc., etc., are just not worth it given the quantities involved?

My final root problem (and there may well be others) is that the demands we are making on our space systems are resulting in more and more complex spacecraft. Aside from the issue of whether the extent of this is really justified, we all know that system reliability is the product of all of the individual part and component reliabilities. The more parts the higher their reliabilities must be and the more difficult the problem becomes from all aspects. Real team dedication and high <u>motivation</u> are required on all of our parts.

Now what can be done to help assure mission success given the foregoing and probably many other factors? I suggest that a good part of the ultimate solution lies in our ability to increase <u>motivation</u> at all levels in government and industry. Back when supervisory and management training was less of a "science" than it is today, I

was personally impressed with the point of view that neither the "carrot" nor the "kick-in-the-pants" approach would really serve to increase motivation. What is really needed is personal and even organizational identification with the task at hand. This is the so-called "hobby" theory that holds that we do the very best we are capable of doing when we are working at a hobby. Why? Because for some reason, or reasons we want to. There are seldom tangible rewards and rarely, if ever, is punishment involved. We become deeply involved and motivated; in other words there is a high degree of identification with the task and desire to see it completed as best we can.

How do we accomplish this? First, some conventional attitudes must change both towards the invididual and towards organizations. We have to weld our engineers, technicians, and assemblers into teams that individuals can identify with. They must understand what they are doing and why. They must feel that they share in the success of the project and that each of their efforts is vital; i.e., we must instill a real sense of pride of accomplishment. We must experiment with new concepts such as giving the team members a greater say in their destiny. Communications must be open and direct. Further, those of us at the higher levels must listen, take action as required, and feed back the results, even if negative. There are many small things that can be done that we often overlook or dismissed as "gimmicks". For example, project insignia that can be put on work coats or clipped on jackets cost little but pay real dividends. Showing films of launchings or piping real time count-down audio into the plant is simple but very popular with the employee. And don't forget to keep the team informed of how things are going after the excitement of lift-off and the early phase of mission check-out is over. Do they know what was really accomplished by the mission and its significance? I know classification is a problem but much can be done if we put our minds to it. "Experience sharing" between aerospace companies and between industry and government could be a useful tool in developing new ideas for increasing motivation and for spreading the word on those which have succeeded and even those that appear to be dead ended. These are only a few almost random ideas on the subject that only scratch the surface. The point is that we must recognize the problem and do something about it. Up to this point, I have talked mostly about individual motivation, but the same thesis applies to whole organizations. Here, our customer, the government must do some re-thinking about organizational motivation. Indeed, I am suggesting that the "carrot" (profit) or "kick-in-the-pants" (a loss on the job and no more contracts) approach is not the single answer to industry motivation. Corporate pride and image are important factors. Having been on the industry side for only a year now it would be presumptuous on my part to make specific suggestions in this connection, but I do feel that it is a fruitful area to address.

To sum it up, I feel that we must stress increasing motivation at all levels because of the clear benefit to many aspects of the problem of increasing mission assurance. Although it is only a part of the final solution, and may not be easy to implement, the potential pay-off is large.

General Morgan, you have challenged industry to help you solve a serious problem. We have responded and this conference is one important result. I can assure you that, working as a team, we will arrive at solutions and implement them. Given our mutual capabilities and desires any other alternative is unthinkable.

GOVERNMENT KEYNOTE ADDRESS

Dr. Eberhardt Rechtin
President, The Aerospace Corporation

Introduction

Ladies and gentlemen, we all know why we're here. We're in a very public business that demands success of a very high order and is going to demand still more. It is perhaps the price of unparalleled success in our space work that space has evolved from the exciting to the unique and essential. Vital questions of space and war are decided based on information from our missions. Command and control of awesome military capability is accomplished increasingly through space elements.

But the systems we provide are individually large investments; few launches cost less than tens of millions and some missions are well over a hundred million. At those prices, we don't have the luxury of warmup tries or statistical score cards. Every mission must work as close to 100% as we can achieve. And we have done well even under these conditions.

But the future holds even more pressure for mission assurance. We are entering a period in which our satellites must not only work, they must work under electronic and perhaps physical attack. Each spacecraft will have to work longer -- as one countermeasure to attack we need to accumulate numbers of spacecraft on orbit at a reasonable cost. Our spacecraft will have to work more independently of ground control as they become more complex, as they are put in space storage, and as they respond intelligently to the unexpected.

I've been asked to give the Government Keynote Address -- and to reiterate the charge we've been given in this conference. We are charged with the urgent need to find effective solutions for the mission assurance problems that stand in the way of continued success in the future. The problems were articulated at informal meetings General Thomas W. Morgan held last fall with key industry leaders. Tomorrow's workshops are organized around the results of those meetings.

Mission Assurance Techniques

All of us can certify that to achieve our levels of reliable performance, we must:

- Define it in the beginning -- success doesn't always mean the same thing to everyone,
- Design for it early -- even in our earliest conceptual thinking,
- Test for it as each subunit is fabricated,
- Search out and eliminate each failure mode as soon as discovered,
- Control the configuration with a vengeance,
- Document even the apparently trival anomaly,
- Instrument with care and intelligence, and then --
- Do it all over again, learning from our errors, when all this still isn't enough.

Since this won't be enough in the future, where can we look for further advancements?

Let me suggest that not only have both government and industry special roles to play, both have special obligations. The government must make timely value judgments, define mission success and stick to it, and accept the product in accordance with pre-established criteria -- i.e., the government customer for spacecraft must be responsible and well informed. The industry must present the government with internally consistent alternatives when value judgments are required, alert it in time for decisions when needed and, of course, supply successful spacecraft and launchers. In addition, each party must hold the other in high respect -- troubles at the interface between them somehow always show up in reduced spacecraft performance on orbit, or at a minimum, waste of precious resources.

With those fundamentals, long since accepted by all of us here, let me start what I hope will be a good list of constructive suggestions from this conference.

1. The government should, early in every program, establish the order of the competing characteristics -- performance, cost, schedule, risk and reliability and then stick to it. We all know that these characteristics are important, but what we design and build is dramatically different depending on their relative priorities. It does the supplier no good at all to say that all characteristics are equally important; worse yet, it sure doesn't help to change the order in mid-program. I was lucky when I was a supplier at JPL years ago to have a government manager who did set the priorities. Because he did, we together built the 210-foot antenna at Goldstone to spec, within schedule, and to cost -- starting with assertions from others that it couldn't be done at all. Time after time, when troubles showed up, the order of competing characteristics pointed the direction. The characteristics, in order, happened to be reliable performance, cost, and then schedule, each having both a minimum and goal. I wish I could say that JPL had always been so lucky. To cite a story of unrelieved misery on this score, read the recently published history of Ranger. To bring the lesson learned up to the present, we will shortly need to know the precedence of survivability, longevity, cost risk, and Shuttle compatibility, relative to the characteristics of performance, cost and schedule we have long designed and built to. It's incumbent on the government, of course, to establish the order of priorities. It's a difficult task. And it has a strong impact on mission assurance. Furthermore, it's even harder to stick to the order, particularly if cost is not first in priority, when the going gets rough.

2. The government and industry, together, need to recognize reliability budgets for

what they are -- a continuing call for assessment, redesign and risk apportionment -- and not just a statistical tool of the reliability support office. When the numbers look bad, change the design! When the risks finally look to be as balanced, or as low, as possible, use the reliability budget to design the test program at the subunit level. When all else fails to produce an acceptable reliability budget, go back and change the requirements. But, above all, don't just plow blindly ahead, accepting whatever "the state-of-the-art" seems to produce. One thing about reliability budgets, as the program proceeds, they seldom get better and they usually get worse.

3. The industry needs to help the government on MILSPECS -- that hard-bought repository of our joint corporate memory. That memory is remarkably good -- commercial industry uses it, selectively, because it makes for reliable and profitable products -- but it can be faulty or obsolete. Somehow, we need to establish an environment where industry can contribute to change easily. The DSB Panel on Unreasonable Specifications found, a few years ago, that for all the frustrations expressed over MILSPECS, very little practical feedback for correction was occurring. In our tight little community surely we can and must do better. Our progress in the evolution of the Class S line of space reliable piece parts shows that this government/industry interchange is possible.

4. I believe the government should provide considerably more publicity for the contractors on both successes and failures. It should put out publicity on spacecraft longevity and launch successes -- by contractor team. It is my strong impression, going back 30 years, that the contractors get all too little public recognition from the government and that this lack of recognition is felt by the employees who do the work that results in mission assurance. This lack is too often perceived as "the government has successes and the industry has failures." That perception is no help. But, when the government does its public relations well, I've observed what I call "the supermarket effect." This beneficent effect occurs in supermarkets when employees' spouses are greeted by their friends with, "I see that TRW (or Hughes or Rockwell . . . .) just put up another successful satellite! Was your husband in that project?" The joint satisfaction of the spouse and the employee can be pretty strong. Their mutual disappointment at failure is also stronger than that of the employee alone. Thus, more government publicity for contractors should, and does, work to the government's advantage. Remember World War II when everyone knew of Martin bombers, Lockheed P-38's and Kaiser ships? Do we, in this gathering, really need to remind ourselves that we succeed or fail together and that we should stand up and be counted, together, before the country?

5. I'll close with one for the researchers. Our community is beset with piece part and subcontractor supply problems. We buy only small quantities of things on which we put extraordinary specifications. To the suppliers, there is often little or no profit in it and seldom even prestige. What more can we do about it? We have already tried special production lines, special QC certification, special testing -- all expensive. So let me suggest we also create markets for inherently reliable processes much as we created the market that made integrated circuits a reality. According to Bob Noyce, President of INTEL, transistors, integrated circuits and microprocessors were developed in an almost explosive fashion when the government created a market for them -- a market rapidly exceeded by a latent commercial market. If you look, today, at where the greatest reliability improvement has been realized, by a factor of not 10% or so but by a factor of <u>thousands</u>, it is in the reliability per function in computing. This reliability improvement came from new processes permitting more functions per chip on chips of increasing perfection. Of course, the temptation is to use the new chips to carry out more functions, but we might do much better to trade off for more reliability of a somewhat lesser number of functions. "Fault-tolerant" computers do just that. Solid state electronics is now increasingly substituting for mechanical elements in such mundane products as typewriters, printers, displays, and actuators. Where else can we repeat the process? Laser fabrication? Laser propulsion? Composite materials? Solid array antennas? Remember, the trick was not to go out and fund developments, but to recognize a new technique, understand its system significance, and generate the market for it that gets private industry going.

So, there are some ideas, some probably better than others. No doubt we will get together a year hence -- our problems won't have gone away. Perhaps we should review our ideas from this conference then and see if and where we've made progress.

AFFORDABLE MISSION ASSURANCE

Major. General Dewey K.K. Lowe
Director of Procurement Policy
Headquarters, U.S. Air Force

Good Afternoon Ladies and Gentlemen

Thank you for inviting me to share some of my views with you at this important industry/SAMSO conference on mission assurance. You, as key space industry executives play a very important role in what I have to say,

Where you sit and what you know often provide you with a different perspective than you might otherwise have. And that's true with respect to mission assurance. One of my favorite stories illustrates the point. Back a few years, when train travel was more prevalent, an overbearing company president took a business trip with his very young junior partner. He sent the young man ahead to get a private compartment but the assistant returned with the bad news that the best he could do was share one. When the president arrived at the shared compartment, he detected a little bit of collusion in that, sitting in the seat facing theirs was a lovely young lady. She was accompanied by a matronly woman - perhaps her mother, her aunt, whatever - but obviously a chaperone.

The two businessmen settled in, and not a word was exchanged as the train pulled out. A short way into the journey, the train entered a tunnel and for a minute the car was pitch black. In that short time, there were two distinct sounds - a kiss and a slap. Then the train was back into the daylight, and the foursome resumed their stony silence. Each mulled the situation over in his and her own mind - each from a different position, and with different knowledge.

The cute young thing thought, "Gee, I was hoping the young man would do that, he certainly is a dashing and handsome fellow, but I wish Grandma hadn't hit him so hard."

Grandma was fuming to herself, "What has this world come to, you can't even ride on the train without some masher trying to take advantage - but my granddaughter took care of him - he won't ever do that again."

The old president was reassessing his young junior partner - "Well, maybe he is a little more bold than I thought - maybe he will turn out to be the kind of aggressive guy I want for the Chicago office - but why did the young lady have to smack me?"

And, of course, the junior partner, sitting in the right spot with all the information was saying to himself, "What a great day, not only did I get to kiss that pretty girl, I got to slap the old man too."

You see, where you sit and the information you have give you a little different perspective. For the junior partner, his planning; design; production, process control; motivational incentives; program or situational review: and experience sharing -- issues of your mission assurance workshops -- all came together for him in achieving mission assurance. His mission was to kiss the beautiful young lady and to impress the old man - both literally and figuratively. The Air Force's objective, in a broad sense, and stated very simply, is to provide a service - national security of the highest quality - at the lowest cost and to assure instant delivery of our product.

We seek the same goals as management anywhere - effectiveness - which we more often characterize as optimum mission performance - and economy - minimizing our costs, making the dollar go as far as possible. We seek greater efficiency of the fighting man through training and through more effective weapon systems for him to use and we at the same time are striving for economy - which has always been a basic concern of the military - in fact, a principle throughout the history of warfare - described by such phrases as economy of force - economy of effort - economy of resources.

This brings me to the subject of mission assurance. But I want to talk about affordable mission assurance -- not mission assurance at any cost.

With the imposed discipline of the new Zero Based Budgeting system and prioritization of programs by mission categories, we must think and act in terms of affordable mission assurance. If not affordable we will be forced to seek alternative means to achieve that mission assurance. In my view, the B-1 is a case in point.

The B-1 was the Air Force's number one priority weapon system. With the B-1 we were to maintain mission assurance by significantly enhancing the manned bomber leg of the TRIAD - with a much stronger and survivable strategic deterrence force.

But the B-1 Production Program was cancelled because of its high cost -- not only acquisition cost but operating and support cost during its life cycle as well. Now the Air Force is embarking on an alternative course of action to achieve that measure of mission assurance.

So I suggest a change in your assignment -- and its a much tougher assignment. Instead of simply mission assurance, let me suggest that your assignment be "affordable" mission assurance. Unless the system you provide -- and these are the systems for which we have demonstrated and articulated a mission need -- unless they are affordable we will not be able to achieve the scope and depth of mission assurances we really need for our national security.

As I reflect on the fast-paced changes going on in the Defense acquisition environment, I am convinced that innovation, imagination, and the goals of conferences such as this one are very much needed, if we are to successfully meet the acquisition challenges presented by the changing environment.

Let's look at the nature of the environment in which the Department of Defense must accomplish its mission. Some of these remarks may not be new to you, but I believe they bear repeating because they emphasize the seriousness of the dilemma we face in the acquisition business -- they establish the framework for the currently emerging acquisition policy directions in the DoD.

We, Government and Industry, as partners in the defense acquisition business, are working toward a common goal -- a U.S. defense capability second to none. History tells us that the acquisition environment in which we pursue this goal is one of rapid, sometimes drastic change. Events of the past decade illustrate this point vividly. As a nation, we have gone from the peak of the conflict

in Southeast Asia to a time of peace. We've seen the transition from the draft to an all-volunteer military service. We have witnessed a shift in national priorities and goals.

Internationally, we are placing more reliance on our Allies for the cooperative defense of the free world, with a trend toward more industrial collaboration for the acquisition of major defense systems. Domestically, putting men on the moon and ending the war in Southeast Asia have been supplanted by environmental protection, social programs, and energy concerns. The past decade has seen general economic instability - characterized in part by a depressed stock market and spiraling wages and prices. We have also been confronted with a dramatic increase in fuel prices and fuel shortages that were unheard of ten years ago. All of us have been talking about new highs for both our private and corporate utility bills and wondering how high they will continue to rise.

All of these changes have had a great impact on the economics of the Department of Defense. This impact is perhaps best reflected in the DoD budget trends. The proposed DoD FY 79 budget outlays are large in terms of current dollars, but small in other respects. A decade ago in FY 68, DoD's budget outlays accounted for 9.4% of the gross national product and 43.6% of the federal budget. The FY 79 budget is estimated to prepresent 5.1% of the GNP and 23% of the federal budget. Since 1968 we've seen the budget grow in current dollars from $78 billion to its FY 79 estimate of $115 billion. At first glance - a 47% increase. However, converted to constant 1979 dollars, we see a decline from $165.8 billion in 1968 to the present $115 billion level, a 30% decrease.

During this period of declining economic strength, other trends were also affecting DoD. For example, from 1964 to 1977, the total manpower strength of the Air Force declined from about 1,200,000 to 815,000 - 32% decrease. During the same period, manpower costs went up almost 80%. The cost of operating and supporting existing weapons systems was increasing rapidly. The cost of acquiring new systems was increasing rapidly. And with military programs, cost growth became a household word.

Let me be more specific. The Air Force recently submitted its calendar year 1977 report to Congress for selected major acquisition programs. For 12 major Air Force programs, excluding the cancelled B-1, we experience a 6% increase for 1977 - totaling over $2.8 billion -- in one year. And 1977 was a good year for the Air Force. This net increase represents an aggregate of increases and decreases over an entire range of cost categories for the 12 programs. We experienced increases in these categories: Inflation - over $2.5 billion; Quantity Changes - over $250 million; Schedule changes - over $850 million; Engineering - over $400 million; Support - over $50 million Contract overruns and others - about $117 million. These were offset by estimating refinements that reduced costs by about $1.4 billion. These figures tell us that inflation impacts program costs, and that's no surprise. But they reveal that almost every other category of cost is also susceptible to growth. No part of the acquisition formula has been unaffected.

In short, the nature of the defense acquisition environment could be described as one of declining real-term budget in the face of increasing weapon systems acquisition and operating costs. This dilemma embodies the challenge for improving defense acquisition and mission assurance. A number of actions are needed if the defense acquisition process is to remain responsive and efficient in the face of this dilemma. Many significant actions are already underway.

At the legislative level, Senator Chiles has introduced Senate Bill 1264, the Federal Acquisition Act, which if enacted will form a new statutory base for acquisition.

The Office of Federal Procurement Policy has emerged as a powerful force for change in the acquisition process. With the backing of both the Congress and the Office of Management and Budget, OFPP has given high priority to implementation of OMB Circular A-109. A-109 requires us to express our needs in terms of the mission we are trying to satisfy rather than with a particular hardware design with specific performance characteristics. It also emphasizes the competitive exploration of alternative system design concepts in response to mission needs. DoD has implemented this policy and the Air Force has promulgated it to the field. The Air Force submitted its FY 79 RDT&E budget on the basis of mission need. In the future we expect our entire budget to be submitted on that basis.

OFPP has also started the effort to develop a single uniform acquisition regulation for the federal government -- the "FAR" or Federal Acquisition Regulation. The final regulation is to be published in August 1979 and will have far reaching effects on the acquisition process.

Within the Department of Defense a major change has taken place with the merger of the research and engineering function and the procurement function. This is part of an effort to streamline the organization and focus attention on the total acquisition process under the acquisition executive. This is a significant step away from our earlier tendency to make R&D, systems, and follow-on buy decisions in a parochial vacuum -- on a compartment by compartment basis. Believe me, this is not a cosmetic reorganization. It is intended that there be a basic change in our acquisition philosophy. Historically the primary focus of "contracting" people has been on the negotiation of cost or price which likely has little relationship to the total cost to the Government and is only a small part of the acquisition professional's role. There is now the need for "acquisition managers" who think and understand the broad spectrum of acquisition.

There are, of course, many more initiatives that will affect the acquisition business. But let me stop with these and reflect a moment on what these changes say to me and where I believe we need to focus our attention. I think the direction is clear. The initiatives and changes I mentioned are all working to sharpen our focus on the comprehensive management of the total weapon acquisition process. Decreasing buying power, increasing weapon costs, shifts in national priorities, and

common sense have brought us to the point. These trends together with the emphasis on the total acquisition process embody the challenge for mission assurance.

In order to meet this challenge, we must take action in several areas. First, the broad concept of the total acquisition process demands that we place greater emphasis on the application of acquisition techniques that foster interdisciplinary cooperation in sort of a symbiotic way. The techniques that fall under the life cycle cost umbrella are good starting points. In the past few years we have begun shifting from a design-to-unit-cost perspective to a design-to-life-cycle-cost perspective. This approach considers the sum of acquisition, support, and operating costs and demands that maintenance and logistics considerations be considered during the initial engineering design, (yes, even in space programs). We must work together to refine the application of the life cycle cost techniques with the goal in mind of making early attractive rewards possible for contractors who can effectively control and reduce systems life cycle costs by enhanced reliability and maintainability.

Second, we must develop closer ties between program cost estimating and contract pricing. Frequently our program budget cost estimates are based on financial data that bear little resemblance to equivalent data generated by contract pricing. Each set of data is based on different assumptions and different computation techniques. It is little wonder that actual program costs frequently don't match the original estimates. I do not pretend that the marriage of budgetary and contract estimating and pricing will get rid of overruns, but it will certainly contribute to better mutual understanding of the two processes and enable us to better analyze and explain variances and to make the appropriate program decisions. I urge you to exhange ideas and thoughts in this important undertaking.

Third, if we are to successfully deal with cost growth and overruns, and avoid the problems associated with "buy-ins" we must work for more cost realism in proposal evaluation and source selection. This translates into increased emphasis on and better use of most probable cost estimates. We must go beyond merely determining that proposed prices are fair and reasonable-and ask the question: "What is the most likely over-all cost to the government if a contract is awarded to a particular offeror?" That question can embrace development, acquisition, and operating and support costs, or any subset of them depending on the contracting situation. This approach places two important responsibilities on the government. First we must develop accurate estimates of most probable costs. And second, we must fairly and effectively apply the most probable cost estimate as an evaluation factor based on the considered assessment of a proposal's technical deficiencies and the cost delta to be applied to that proposal in assessing the anticipated cost of performance.

This afternoon I have tried to build a perspective around the direction I see the defense acquisition business heading and the need for affordable mission assurance. The trends of the past decade have created a dilemma involving austere budget constraints and increasing defense acquisition and support costs. A number of legislative and policy changes have clearly mapped out the direction for the future -- better management of the total acquisition process.

I think the bottom line for us at this conference, even if we, like the junior partner, work in the dark sometimes - we get the job done, because we have the right perspective - we sit in the right seat and have the right information. It is important to our nation that we continue that way--and it is likewise important that industry understands our perspective so that you can help us. I think you in industry should have a simple time of that - our perspective is so much like your onw. I solicit your continued support and enthusiasm in our efforts to maintain a defense that is second to none.

Thank you.

LESSONS LEARNED FROM MISSION SUCCESS

Walter O. Lowrie
Vice President, MX Program
Martin Marietta

Presentation by Mr. Lowrie

MR. LOWRIE: I really don't know why you're having this symposium. I was down in the Virgin Islands last week and and the privilege of flying in a DC-3. I hadn't been in a DC-3 for so many years, I forgot what they were like. But any country that could produce a DC-3 in the '40s which is still flying in the Virgin Islands, with about half the rivets replaced with bolts that are sticking up into the windstream and gaps everywhere between panels where we aerodynamicists used to be so fussy, doesn't need to worry about Mission Success. It gave me a nightmare. I didn't think we'd ever get off the ground in something as patched up as that, but we made it.

Seriously, for the next half hour, I'd like to share with you some of my observations. I'd like to start with a recap on our heritage in the mission success, mission assurance business, from my point of view, as far as history or where you've been. Then I'd like to reflect on the implications on what I call attitudes towards mission assurance or maybe attitudes that are detrimental to mission assurance and what I have referred to as some of the "myths" of the business.

I won't go clear back to the Wright Brothers or Goddard. I'd like to start in the mid 50's and say where we've come from, from that time. That is the start of the ICBM business. I can reflect back on many meetings we had in those early days on Titan I. There were bitter debates or maybe I should say active debates between some of the RW people and ourselves. For those of you who don't have the memory, that's kind of a forerunner of Aerospace Corporation in generations back. These were debates on how many flight failures we should allow for during the flight test program. You should reflect on that a little bit because we were arguing whether it should be 15 percent or 20 percent or 25 percent failures in flight. That's the start of the business. The implication is very profound, because if your expectation is failure, you have to have an attitude of condoning failure. So that's where we started from 20-some years ago--expectation of 15, 20, 25 percent failure.

I'm not going to give you a big long history dissertation. I'll jump next to the early 60's and the start of Titan III. The first Titan III program was a 17-ship R&D program. Titan III was originally conceived as a core vehicle, which we called the Lot A vehicle on which you could fly small payloads to various orbits. Then you strapped on a pair of solids and you could fly a bunch of other tougher missions. The 17-ship R&D program checked out the different missions and the different flight profiles gradually working up to tougher and tougher missions. There was a kind of underlying implication that there would probably be some failures along the way, because we weren't carrying any active payloads. We were carrying all dummy payloads initially.

I think we had the successes in a row and boy, everybody got excited and the forerunner of SAMSO, I don't remember whether it was BMD or BSD at that time said, "Gee whiz, we're spending a lot af money flying boosters. They're awful damn fine vehicles and we ought to put some bonus payloads on them." That seemed like a jim-dandy idea and so they went around to industry and said, "Hey, you know, we got a nice vehicle that you can get into space with and you ought to come join the party; but be aware it's a bonus payload because it's an R&D program and we can't guarantee you anything." So we started flying some pretty nice little payloads. Then the stuff started to hit the fan, because we had two failures in a row and dumped two payloads in the ocean. They were not the big kind of payloads you have now-a-days, but still, it got everybody in the system up tight.

I'll never forget those times. I had just been appointed the glorious title of Director of Mission Success.

My general manager said that my function in life was to be damn sure we never dropped anything in the ocean from now on. Of course, he didn't count those against me, because that kind of happened before my watch. At that point SAMSO or its forerunner called the Associate Contractor out to the West Coast to a kind of a come-to-God meeting. I think it was Colonel Miller at that time. He lambasted us all and said, "you've all done a lousy goddamn job", and he had a bill of particulars that they'd gone off and gotten on what a lousy job we had really done -- all of us. Then he aaid we've got to be 100 percent successful now that we're flying expensive payloads.

"I want you all to go home for ten days, and then come back and tell us what you're going to do about it." I'll never forget, my general manager and the program manager of Titan III and I got drunk on the airplane going home and mumbling into our beer, "Those bastards, they contracted for an 80 percent reliable product and we're giving them a damn fine product." After we got rid of all that venom, cleaning the spleen, or whatever you want to call it, the next day we sat down and got a little more mature about it. We decided we really ought to take the challenge seriously and so did the other associate contractors. That's really the turning point, at least in our company, and maybe even in much of the industry, of some of the basic attitudes. I'll go into some of those attitudes in a minute.

We did then go through a soul-searching exercise and a moratorium for about a month or six weeks. We went back through all of our test procedures, did a kind of a fault tree analysis from a testing point of view. We found lots of gaps where we could test, should test and were not testing, because we really hadn't done the original job thoroughly enough. We went back and looked at all of our failure histories and we were appalled at what we saw in those fine documents. You all have a spec that says you have to have a corrective action system. We did. We had all sorts of good records, but when you went and looked and you tried to find out what was the physics of the failure -- did we really isolate the failure -- you came away, in many cases, scratching your head. We went and looked at the paperwork that accepts the hardware, and came away building a cage for rejected hardware because the paperwork wouldn't support its acceptability. You didn't know whether it was

a paperwork problem or a real hardware problem. In many cases, we went back to the vendors and got the primary data, test dates or other things and found out, yes it was, in fact, good hardware and people were just sloppy with the paperwork. In other cases, we had to retest hardware. In still other cases, we found problems and rejected hardware. It was a real gut wrenching exercise. We found out, down in the guts of our operation, we weren't doing nearly as good a job as we thought we were.

Moving ahead in history a little bit later, John Naugle of NASA asked a couple of us to come in and talk to him. He'd had two or three failures on the Delta program. He was pretty concerned about what he should do. Coincidently, I'd been to a Delta Users symposium at Goddard two weeks earlier because I was about to go bid on a thing called Planetary Explorer. This Planetary Explorer was one-of-a-kind spacecraft. I was sitting in the audience as a potential user and the man on the stage was very blantantly telling me, "You're a user, if you are going to fly four or five payloads, you ought to expect one going in the ocean, because this is an 80 percent reliable booster and therefore you should expect failure." That kind of wrenched my gut a little bit as a user. So anyway, when we were talking to John we talked all the good things they were going to do in their shops, with their parts, with their testing and all that kind of thing. At one point I turned to John and said, "You know what your primary problem is?" He paused and I said, "It's you!" I knew John pretty well and I wanted to shock him. I said, "You sat in the audience with me and you let some of your people in the lower levels of your organization condone failure. Management can't condone failure." Now, that is not an unrealistic statement. Failure is going to occur. I understand that. I've lived in the real world, just like the rest of you, but management can never put themselves in a position in our kind of business of condoning failure or saying, "I expect a 20 percent fallout." But that's where our heritage has been in this industry and we're not out of it yet.

I don't want to put myself in the position of crowing, but I would like to talk Viking a little bit, to illustrate that the industry has matured. We've come an awfully long way. In 1969 Martin Marietta contracted for Viking with NASA and over half of the fee of that contract was to be an objective award fee by NASA based on the return of science data from Mars. Now that's a pretty gutsy proposition. You're betting a lot of money and a lot of corporate investment on being successful and delivering the merchandise on a one-of-a-kind type program. We're not alone. There are other companies that are doing the same sort of things. There are a number of satellite programs now that are required to live in space for many years and produce part of their fees from incentive awards based on performance. We have come a long way and we have demonstrated, as an industry, that we can do things like Viking. On that program we had 14 major subcontractors -- many of them very big companies in the industry -- some of them I see here today. All of them pulling a big chunk of the weight that produced Viking. So the industry can produce that kind of results. I went through that history because I think sometimes it is important to understand where you've come from to understand maybe where it is you've got to go. I want to talk now about some of the myths and attitudes I've seen along the way.

The first thing is that question of attitude toward failure. I think it's absolutely fundamental and I think you all have to look in the mirror and say, "Are we guilty of expecting failure and therefore passing on down through the organization, an image of condoning failure?" Because that reflects very much in the performance of the total organization.

I have two or three other myths I want to go over in the time available. I'm going to the trenches--down to the working level of the mission assurance business. The first myth I call the personnel error myth. If I go back ten or fifteen years, it was rampant throughout the industry, but it is still pretty prevalent. You go down in your organization and look at your failure records. Examine them. You'll probably find many cases where it says, "Cause of failure, personnel error--corrective Action, personnel warned." That's phoney in most cases. The personnel error myth or whatever you want to call it, is a trap because it's a garbage can for hiding all sorts of other things. Personnel do make mistakes, and I'm not against motivation programs to minimize that, I think we would have them. They're great, particularly to get management and supervision to talk to the worker. That gets him motivated, but it gets him motivated because he begins to understand what's going on and what is expected.

However, there are many, many cases - and I'll just use one as an example out of our own company -- of so-called personnel error that aren't that at all. They're supervision error or management error. The example I'm going to use is a few years back, but we can find them every day. I got a call one day from the Cape that said, "Gee, one of our bumble-headed workers put a foot over on the side of the boat tail and knocked off a transducer; now we got to delay the launch for two days, because we can't get the thing replaced." Well, I knew the boat tail on a Titan is a cramped place to work so when the general manager came running in my office and said, "Have you fired him or given him five days off?" I said, "We're investigating." "What do you mean you're investigating? He kicked the transducer." Well, the investigation showed that, as I said, the guy has to crawl in a tight area and he has got to get into a posture where he is reaching up high. We didn't give him a work platform and we had, for several birds, been allowing the the workmen to slide a two-by-six across two frames and then crawl in on the two-by-six, stand erect and brace himself. In order to keep his balance he had to put his foot on the side of the launch vehicle. That was the work environment we gave that poor son-of-a-gun to work in. Now whose fault is it the transducer got kicked? It's obviously management or supervision.

The supervisor had been watching that go on and hadn't screamed. If you carefully examine so-called personnel error, in almost all cases, you'll find somebody needs some training, or education, or a better tool, or a better work environment or something else. He doesn't need to be cautioned, in most cases. The thing I would challenge you to go do, is look at your various companies and see if you're using personnel error

as a trap for getting around working to correct the real problems.

The next myth I want to talk about is the corrective action system itself. Everyone has a closed loop corrective action system. Every company I've ever gone into in the United States beats their breast, shows a viewgraph of their closed loop corrective action system. Of course, they have one, the specs require that they have them, but if you go down in the bowels and examine how they run it, you find sometimes it's pretty shoddy in the quality of implementation. So I say it's a myth in the sense of the quality of the implementation.

One of the things we started back in the Titan III trauma days was an education of our engineers and testers and quality engineers, to treat all failures with the same rigor as if it was a flight failure. That requires that you must get to the physics of the failure. You must isolate the fault and must take corrective action or bump it up to the project manager. That way no problems are hiding down there in the woodwork.

The thing I find that we, as an industry, still have to go a long ways to do better in this concept of cause isolation from a system level clear down to the parts level into the physics of failure. Let me illustrate what I'm talking about.

If I have a black box failure in the shop and I isolate the problem to a module and I take the module out, and then put a new module in and I go test the box and it seems to work great, there are still a lot of people in the industry saying, "Aha, that's a good piece of merchandise." That isn't necessarily true. The first thing I have to do is verify in fact the removed module is bad and then I'm only halfway there. I also have to verify that the fault in the module is such that it was not induced by something else in the black box, or I have not done proper fault isolation. Otherwise I run the risk of having a hidden problem in the box that will bite me later.

Another technique which got introduced into the Titan family back at that point in time, and which we have used on all programs since, is the unverified failure discipline. We, in fact, did fly two pieces of hardware that had unverified failures on Viking, but I'll tell you, there were a lot of agonizing meetings between Jim Martin, who was the NASA Program Director, and myself, before we bought off on them. They were specific instruments, so that they could't be mission catastrophic, but we could have lost an instrument. We had a system that allowed us to know where the risks specifically were. If you're dealing with any kind of a high reliability system, you had better have that kind of discipline where the project manager or technical director or somebody at the top level of the project, personally assesses the risk and buys off on the risk, or you're not managing your risks. Your program is drifting along, essentially out of control, from a mission success point of view.

The next on I'll call the digital myth. I noticed this myth a few years ago as digital systems became more prevalent in the aerospace world. During the Viking days, one of our subcontractors, who will go unmentioned, was producing digital airborne equipment. Most of the people in his organization had an ingrained attitude, "Well, it's digital equipment and therefore you should expect ghosts or funnies to happen from time to time." One day I was walking through the shop where we were testing one of our first pieces of flight hardware add I was watching the guy running the system-level test on this box. I wasn't specifically familiar with the details of the test, but I could sort of see generally what was going on and something appeared funny and he stopped and flipped the switch. It looked to me like it was a repeat, so I asked him. He said, "Oh yeah, that was a glitch, it appears once in a while." I said, "What do you do?" "Well, I reinitialize." No documentation! This is a modern-day contractor in our business, and it isn't just true of that particular contractor. The feeling was -- well, digital equipment you know, has those kinds of things. It's susceptible to it. That's baloney! That just says you don't know your margins and you haven't designed the system properly. When we got into the nitty-gritty of the problem, we found we had test equipment in that shop that was putting out so damn much noise, we didn't know what we were testing. When we got through spending about three months cleaning up the test equipment, because it was a tough job, then we found out we had some design problems in the equipment because of the pulse rate and shape and what have you. We really had lots of little design areas in the packaging where there were little RF generators that we had to eliminate. After we got all done cleaning it up, we never had any more glitches. It was really bloody and I had to go all the way to the general manager of the facility and he was the only man in the facility that could understand my language and he had to go down and educate his people, all the way down through the line, because they had spent so many years with this myth that digital equipment always had glitches from time to time that were unexplainable and you had to live with it. You shouldn't live with it because they are dangerous.

The last one I want to talk about is what I'll call the software change myth. I don't know how much you're going to get into software here in your workshops or talks, but software certainly from a mission success point of view, ought to have equal emphasis to hardware. I don't think it gets enough. We are beginning to pay a lot of attention to it in our company. There is a prevalent attitude and there has been for a number of years, that when you begin to get into the inevitable problems in system or spacecraft development, you can fix them easiest with software. You get your bright young guy that can code a piece of software and he says, "I got the invention to cure your problem. I'll just put a jumper in and put a patch in and do this, that and the other for you, and the problem's fixed." And oh, he can do that. He can do that almost over night. He brings his little deck of cards and he runs it and provides a new tape and gee, you're happy because the machine works. But you have just bought a piece of the farm potentially. You have invalidated your software, most probably. We've all been guilty of doing that to some degree in the past. We really have to understand the total implication of a software change including its retest and revalidation. The cost of that software change is often as much as the hardware change, because you have an extensive test program you should rerun, to have the same degree of assurance that you had before you made the change. You tend to slide by that fact time after time because you're in such a box. The

guy says, "God, if I got to change the hardware, I got to go back and order new PC boards or some other traumatic thing." It's so easy to create that deck of cards and forget the validation that you really should go through to provide the same assurance.

I guess my half hour's about up. I selected those particular items. I could go on for many hours. I selected those particular items because they were the things that came bubbling into my mind, foremost, that are the traps that I think we all have to pay more attention to stamping out. I just said, we've come a long ways from those early days when we really expected a lot of failures. We have a lot of people in this romm that are producing very high quality hardware now, that is, in fact, performing in space for years, and is expected to perform years more.

In my tours around the industry, I observe there are still these kind of traps. We have to get down into the bowels of our organization and see if we're really performing some of the things the way we say or the way we think we're doing. We've got to improve on the quality of our implementation.

PIECE PARTS PANEL

Col. William Schlosser, Moderator
Director of Acquisition Support SAMSO

PANEL OVERVIEW AND OBJECTIVES

Col. William Schlosser
Director of Acquisition Support, SAMSO

The purposes of this panel are:

1. Present to you summary views of various aspects of piece parts management for mission assurance from various perspectives: i.e., SAMSO, NASA, DESC, and industry.

2. Stimulate discussion that will identify and clarify the issues involved in piece parts management for assurance of space mission success.

The Challenge

There is a challenge, common to all these space missions and systems: the challenge to assure mission success.

Speaking in terms of piece parts, assuring success of space missions is indeed a complex and demanding challenge.

SAMSO space systems and missions are continually increasing in complexity. Successful on-orbit operations for SAMSO systems are now required to live without failure for as much as 10 years. In a system with up to 70,000 piece parts and no on-orbit maintenance possible, achieving 10 years of reliability is indeed a challenge!

Secondly, space satellite failures can be caused by any one of the thousands of electronic parts that comprise an on-orbit system. Redundancy can help reduce failure risk, but a common failure mechanism in the electronic parts of redundant units can still cause system failure. Every part of a long life space system must be of the highest quality to prevent premature failure.

Thirdly, small quantity buys, long lead delivery schedules, market influence fluctuations, program peculiar spec. requirements, costly qualification programs and lack of available space quality parts have caused many procurement and schedule problems in our programs.

And after we had received the parts, SAMSO has experienced several costly flight and ground failures attributed to faulty electronic parts.

For example, one of our major space communications programs was affected by failure of a launch vehicle. We lost 2 satellites at a cost of \$57 million to replace, and a significant lapse in DoD space communications. This failure was caused by a particle short in a single transistor.

Total Parts Management

Meeting this challenge of space mission assurance requires nothing short of total management of these critical and numerous piece parts.

Since any single part can cause mission failure, every piece part (every type and every part and lot of parts) must be managed in a way that will increase reliability and reduce the risk of failure.

All piece parts must be managed throughout their life cycle if space quality is to be assured. Parts management and reliability assurance must start with the design and selection of parts used in a system and continue throughout the application, manufacture, procurement, and operation of these parts. Mismanagement at any step can cause mission failure.

It is very easy in the very complex, microscopic business of piece parts to lock onto one issue or another as the key. Granted, that is the way to address and solve that issue. However, space mission success requires total and continual management of all of the aspects and issues involved in achieving space quality and reliability in all system piece parts.

New SAMSO Parts Policies

For many years, SAMSO's policy on piece parts has been to require (1) use of the highest reliability parts obtainable and (2) management of part selection via a part control program/board.

During the past year, SAMSO has searched for other techniques for assuring space quality parts are used in all space missions.

The 3 new policies shown here have been adopted by SAMSO and approved by the SAMSO commander for implementation on SAMSO programs.

The class "S" parts program is a joint SAMSO, NASA, DESC, RADC, industry effort to create military standard, certified, qualified, available space quality microcircuits and semiconductors for use in SAMSO and NASA missions. Other panel members will discuss the class "S" program in more detail.

Coordinated procurement by each program prime contractor is expected to reduce part procurement difficulties, improve standardization, reduce small quantity buys, and improve subcontractor parts procurement management. Several programs (e.g., ;AFSP and NASA/Viking) have successfully implemented coordinated procurements.

Monitoring of the part manufacturer's processing and testing of program parts has proven successful on several programs. SAMSO intends to implement line monitoring by the program prime contractor to assure that the parts delivered for space missions are truly space quality.

Benefits

Use of class "S" parts and line monitoring will result in higher reliability parts in space and launch vehicle systems. They will reduce failures, schedule delays, rework and retest, and program costs.

Class "S" parts, available in the military QPL will reduce procurement difficulties and eliminate the need for costly, duplicative contractor specification and qualification efforts.

Common SAMSO/NASA/Industry class "S" requirements will reduce the proliferation of program/company unique specs and low volume unique parts. God knows we need less paperwork and less legal staff to read and interpret it.

Joint SAMSO/NASA use of class "S" parts and implementation of space program coordinated procurements will increase the procurement volume per buy to the vendor, increase vendor interest in class "S" parts, and improve both the reliability and availability of space quality parts.

THE IMPORTANCE OF ELECTRONIC PARTS STANDARDIZATION THROUGH THE MILITARY SPECIFICATION SYSTEM

Brigadier General George K. Patterson
Commander, DESC

I welcome this opportunity today to discuss with you the national significance of military specifications for electronic parts standardization to enhance the mission assurance of space programs.

As commander of an organization responsible for integrated management of one-sixth of all items managed by the U.S. Government, I am, understandably, also charged with the task of managing and conducting a comprehensive DoD standardization program for electronic parts, used in a tremendously wide variety of applications. This engineering standardization mission at the Defense Electronics Supply Center (or DESC) is assigned to my directorate of engineering standardization and is under the guidance of Colonel Loren Anderson. To do his job, "Andy" supervises the actions of some 200 engineering personnel, three-fourths of them electronic engineers and electronic technicians.

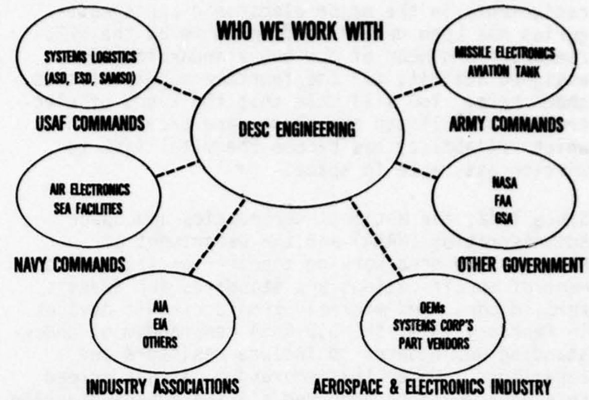
The roots of the engineering standardization mission for electronic parts at DESC run deep and date back to the Army Signal Corps at Fort Monmouth, New Jersey, in 1943. By 1949 the organization became a tri-service agency and was better known as ASESA. When DESC was established in 1962, the functions and workloads for specifications, standards, and product qualification were transferred to DESC and the directorate of engineering standardization formed.

The main mission of my engineering directorate is to provide standardization support services to the military departments.

One of our most important jobs is to provide parts control support for systems program managers. In fiscal year 1978 we have provided parts control assistance to 284 design contracts. DESC engineers have provided recommendations on the selection of 40,000 electronic part types and on the adequacy of 7000 drawings. The life cycle cost avoidance achieved from our efforts this year is in excess of $110 million.

The backbone of the electronic parts control program at DESC is built upon our mission as an agent for the military departments in the preparation of military specifications and military standards and the administration of qualified products lists (QPLs). In the electronic part supply classes, DESC engineers serve as an agent for the military departments on more than 90% of the specs and standards projects established. In a given year we issue more than 1,200 standardization documents impacting an estimated 50,000 parts. In the qualifications area, we administer QPLs for 150 general military specifications for electronic parts. In a typical year, we audit more than 200 facilities and evaluate over 1,000 test reports covering thousands of product types.

DESC's technical capability and involvement in the development of specifications led the DoD to designate us as the DoD standardization manager for fourteen federal supply classes, covering parts in the dynamic electronic part technologies.



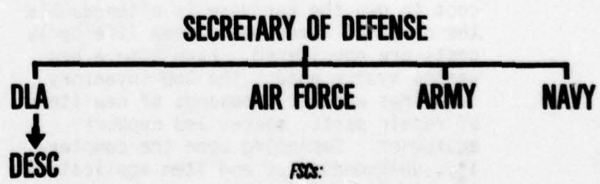
As you see from this diagram, DESC is not working in a vacuum. As the DoD standardization manager, we must work closely with engineers in government and industry in developing an effective parts standardization program. Based upon the needs and inputs from the organizations shown here, we write more military specifications and standards for electronic parts than all other organizations combined in the DoD.

In the Department of Defense, standardization is the law and not a luxury. Under title 10 of the U.S. code, the Secretary of Defense has been directed to standardize parts to the highest degree practicable. A few of the objectives cited in Section 2451 of the code are quite appropriate to my message today.

In managing an effective standardization program we are required to standardize complex electronic items by developing and using single specifications and eliminating overlapping and duplicate documents describing parts, materials and processes that are generally similar.

While developing a single set of specifications we must also make efficient use of the existing services and facilities for inspecting, testing and accepting items procured to military requirements.

MANAGEMENT OF THE DoD STANDARDIZATION PROGRAM



FSCs:

5905	Resistors	5945	Relays
5910	Capacitors	5950	Transformers Coils
5915	Filters	5960	Tubes
5920	Fuses	5961	Transistors Diodes
5925	Circuit Breakers	5962	Microelectronic Circuit Devices
5930	Switches		
5935	Connectors	5985	Waveguides
		5999	Misc Electronics

The authority to act for the Secretary of Defense within the scope of standardization management

assignments in the major electronic parts categories has been delegated down to me as the DESC commander and head of the DoD standardization assignee activity for the fourteen supply classes shown here. You will note that the kinds of electronic parts listed are those same products in which reliability has become the vital link to mission assurance in space.

Since 1972, the National Aeronautics and Space Administration (NASA) and the Department of Defense have been working together on the development of specifications and standards for transistors, diodes, and microelectronic circuit devices. In February 1974, the DoD-NASA memorandum of understanding was updated to include resistors and capacitors. Under the memorandum, it was agreed that NASA would be accorded all the standardization authority and responsibility comparable to that of the Army, Navy and Air Force. As you can see, NASA is now a very important facet in four of the fourteen FSCs delegated to me for standardization mangement.

Standardization has long been an important element of military logistics, design, research and engineering. From a national standpoint, it has often provided the essential ingredient for profitable production and distribution of goods in the civilian market.

In the electronic parts area, standardization represents a 35 year evolution of effort practiced by the military services in establishing contract requirements.

However, lessons learned from World War II, Korea, South East Asia and the intervening state of international tension, visibly demonstrate a national need for management attention to the standardization of highly reliable parts for space, missile and avionic applications.

In today's world the problems driving the need for standardization through the military specification system are easily apparent:

1. While electronic equipment is extremely complex and costly, the available real dollars in DoD and NASA to buy such hardware is diminishing.

2. When we can afford to buy, we find the cost to own the hardware is often double the original investment, when life cycle costs are considered. Each time a new weapon system enters the DoD inventory it brings with it thousands of new items of repair parts, spares and support equipment. Depending upon the complexity, uniqueness and end item application of a particular device type, the cost impact to document and test could range from $2,000 to $25,000 for the nonstandard part type applied in a new design. Considering the quantity of nonstandard parts used in a typical development program, the engineering and testing cost for nonstandard items is becoming prohibitive.

3. Manufacturers of equipment and systems are frequently faced with the fact that parts and components are not available to meet the ever increasing demand for better reliability, maintainability, transportability, and performance. The net result is a great volume of engineering talent and money expended in searching for improvdd parts and inspecting and testing such parts to verify and assure reliability.

4. The independent solution by each contractor of the problem is often the development of a new nonstandard part. These independent solutions to the same problem result in a steady increase in the number of varieties of items and a wasteful duplicative effort in development, testing and inspection. Resources will continue to be diverted until all our designers, engineers and logistic managers have and use up-to-date specifications, standards and QPLs which contain solutions to these repetitive problems.

The improper use of specifications and standards are a cause of much concern. The Office of Management and budget and the Under Secretary of Defense for Research and Engineering are now taking a detailed look at the origination, maintenance and application of specifications and standards. Both Congress and the General Accounting Office have condemned specs and standards as sources of poor performance, goldplating, excessive delays, and unnecessary costs. In July 1974, at the request of DoD, the Defense Science Board created a task force on specifications and standards with a primary objective of developing recommendations for improving the use of these documents.

In April 1977, the report of the task force on specifications and standards (or SHEA Report) identified many documents containing procedure techniques considered to be a major factor in driving costs when misused or not tailored to the specific needs of a program. Most of the documents identified as cost drivers in the SHEA Report are the "illity" documents used for general design requirements, environmental requirements, test methods, reliability, maintainability, configuration control, human factors, safety and other similar documentation.

The SHEA Report recognized the need for assuring that essential operational capability requirements were not sacrificed when tailoring requirements to support a particular system. On the other hand, the report was quite clear in its claim that DoD was over-applying and mis-using its specifications and standards.

We were pleased with the comment in the SHEA Report concerning the progress made by DESC in the parts control program and in managing standardization effort for electronics parts. The joint effort of DESC, the military departments, NASA, other government agencies and trade associations has made military specifications and standards the "National Corporate Memory" for electronic parts procurement and standardization. We now have the opportunity to apply this "National Corporate Memory" to electronic parts used in the space mission environment.

Recently it was my pleasure to sign a joint agreement between SAMSO, NASA, and DESC on operating procedures governing the administration and technical aspects of microcircuit certification requirements of MIL-M-38510D add MIL-STD-976.

I believe we have achieved a significant milestone in the evolution of Class S parts under the umbrella of MIL-M-38510D. More significantly, the joining of DESC, NASA and SAMSO to invoke the Class S qualification and certification program is a money winner all the way.

In the past, we three have been essentially operating on our own to qualify high reliability parts. DESC has administered qualification for Class B and C devices, and has authorized testing and evaluated test reports for the old Class A devices. NASA has conducted their own line certification audits for the old Class A devices. SAMSO has been administering their own quality program under MIL-M-38510B. The net result has been duplication and overlap of audits at the manufacturers' plants by the three activities. In addition to audit overlap, audit uniformity and consistency have suffered. Now that the new Class S had been placed under MIL-M-38510D, superseding MIL-M-38510B, and MIL-STD-976 has been issued, a new look has been taken at the qualification and certification requirements of microcircuits.

I would like to explain how DESC, SAMSO, and NASA will work together in the Class S qualification program. The Defense Electronics Supply Center, DESC-EQ, as the DoD focal point for the JAN microcircuit program, will perform all administrative work on Class S devices. This includes paperwork involved in the qualification of microcircuits and the certification of manufacturers' facilities. DESC, NASA, and SAMSO will agree on a chairman for an audit. For potential Class S line audits, chairmanship will normally be either NASA or SAMSO. Following an audit, DESC will issue audit deficiency letters, coordinate corrective actions, issue certification letters, authorize testing, evaluate test reports, and issue notification of qualification. For Class "S" devices NASA and SAMSO will be voting members on the technical aspects of DESC administrative actions.

The key point in Class S certification is the provision for a joint team audit composed of individual members from each government activity that has an interest. This will result in several advantages:

1. Minimize company's time spent during audits

2. Eliminate audit duplication and overlap

3. Reduce overall audit expenses

4. Improve uniformity of audits

To effect this last advantage, we plan to restrict the number of participants performing the audit to provide an efficient team. Only the people essential for the audit will be in attendance. This will ensure cost effectiveness and provide a uniform audit in minimum time.

A significant ingredient for a successful qualification program is fair and equitable treatment of all manufacturers. We need to be on guard that the requirements which we set forth are in fact needed and realistic and that they will satisfy our needs. Fair and equitable treatment will be improved through the joint efforts of DESC, NASA, and SAMSO. Another significant ingredient for a successful qualification program is a market for devices. The market place for Class S devices should now be enhanced through the combined usage of both NASA and SAMSO.

Aside from the qualification program, other goals need to be accomplished. With the incorporation of class S devices in MIL-M-38510D, we plan to strive to establish Class S devices in other electronic part categories as well.

Let us take a look at future Class S activity in other mil specs.

In December 1977, DESC as agent for the Naval Electronic Systems Command Preparing activity, revised MIL-S-19500, the general specification for semiconductors. By Revision F to MIL-S-19500, Class "S" space parts requirements were placed in the document. The JAN Class "S" is the fourth and highest level of product assurance in MIL-S-19500 and is preferred in space equipment over the lower assurance levels such as JAN, JANTX, and JANTXV. Audits of JAN S certified lines are required by Section 3 of the specification. The audit team procedure will follow the same procedure as used in MIL-M-38510.

We are now taking a look at some of the other mil specs that may be adaptable to the Class S concept. Established reliability or "ER" specifications for resistors and capacitors are now under consideration. We are also examining other mil specs covering product areas such as EMI filters, switches, relays, connectors, crystals and RF coils.

We are optimistic that the mil spec system for electronic piece parts can be adapted to the complex mission assurance needs of space and missile programs. I believe it will be a major milestone in the achievement of our expectations in the awakening of a new mil spec standardization system in the best interests of the nation.

GENERAL OBSERVATIONS ON PARTS MANAGEMENT AND A REVIEW OF THE GPS EXPERIENCE

Martin L. Adams
Manager, Systems Effectiveness
Rockwell International

Observations

1. On GPS EEE parts are 98 percent of the functional elements of the Satellite-Huge opportunity for management techniques to influence reliability of S/C thru the parts program.

2. Critical Areas to be Aware of

   a. Understand Requirements

      Management may not fully understand the technical requirements, and underestimate the cost and staff requirements.

      e.g., It may not be clear that the JAN and ER devices require rescreening.

   b. Lead Times

      Ambitious vehicle schedules may ignore the real parts lead times. SAMSO has to lead here, because no bidder wants to degrade his competitiveness by realistically assessing that the parts program lead times may not support the hardware needs. Later, Mission Assurance may be degraded because of compromises in part pedigree to meet schedules.

   c. Parts Not Available

      Know in advance that except for Class S microcircuits, parts meeting SAMSO requirements are not procurable off-the-shelf. Also, because of low volume and special processing controls, manufacturers may not be cooperative.

      There are some techniques to overcome mfr. resistance which we have successfully deployed and will discuss later.

After framing the above issues, - then discuss the GPS experience -

On the first 6 systems -

1. Took careful effort to assure all subcontractors understood requirements.

   a. Visits to each

   b. Overall conference

2. Quickly assessed that the small suppliers and low volume users needed help.

3. Developed a pooled procurement concentrating on using screening facility to upgrade parts.

4. Overloaded the screening agency and had to inject massive management and technical effort to make deliveries.

5. Overall - excellent quality parts were achieved but cost was too high and schedule risks were unacceptable. A better technique was needed.

On the follow-on 2 vehicles we had an opportunity to pioneer a better approach.

Better Approach

1. A pooled procurement - emphasis on using the original mfr. to do the rescreening, with less reliance on screening facility.

2. After agreement with each subcontractor on parts to be pooled, quantity, need date, RI prepared specifications and negotiated with manufacturers for best price and delivery.

3. RI placed master P.O. and subcontractors issued independent P.O.'s referencing the master P.O.

4. RI provided technical management, source inspection, status reporting and performed most of the DPA's.

5. Manufacturer delivered parts and data directly to subcontractor.

Advantages

1. Risks spread over 20 manufacturers and one screening facility.

2. Most schedules met or exceeded.

3. Manufacturer put in extra effort because of size and $ value of order and awareness of requirements that must be met for lot acceptance.

4. Substantial cost savings due to larger quantities, elimination of multiple lot charges (DPA's, SEM, lot minim's) and centralization of PQA, technical and administrative support.

Challenges for SAMSO

1. Take the lead in making the "S" type parts available for more circuit types and styles.

2. Encourage schedule realism in proposals.

GENERAL OBSERVATIONS ON PARTS MANAGEMENT AND THE DSCS III PROGRAM EXPERIENCE

Paul Dick
Manager, Product Assurance, DSCS III
General Electric Company

THREE KEY ELEMENTS OF NEW SAMSO PARTS POLICIES

1 – CLASS "S" PARTS USAGE
2 – COORDINATED PROCUREMENT
3 – PART MANUFACTURER MONITORING

GENERAL ELECTRIC'S APPLICATION OF THESE THREE KEY CONCEPTS TO THE DSCS III PROGRAM

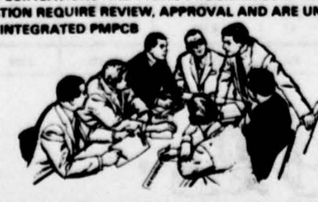
1 – HIGHEST RELIABILITY PART USAGE
2 – PROGRAM INTEGRATED PARTS SYSTEM (PIPS)
3 – PARTS QUALITY MONITORING ACTIVITIES

1 – HIGHEST RELIABILITY PARTS USAGE

- PARTS PROGRAM CONTROL DOCUMENTATION
  - PROGRAM PLAN – SUPPORT PROCEDURES – SPECIFICATIONS
- USE IS MADE OF 18 TYPES OF THE ORIGINAL CLASS "S" TTL LOW POWER MICROCIRCUITS ON MIL-M-0038510
- OTHER ACTIVE DEVICES (SEMICONDUCTORS AND IC'S) AND UNIQUE PASSIVES ARE PROCURED TO "TECHNICALLY EQUIVALENT S CLASS" REQUIREMENT SPECIFICATIONS PREPARED BY GE
- COMMON TYPE PASSIVES ARE PROCURED TO HIGHEST RELIABILITY LEVEL POSSIBLE CONSISTENT WITH UPGRADED ER-MIL REQUIREMENTS
- SPECIAL DEVICES GIVEN ADDITIONAL STRONG CONTROLS
  - LSI's – GAAsFET's – CMOS – HYBRIDS – CHIPS

DSCS III PARTS PROGRAM CONTROL DOCUMENTATION

- PREFERRED PARTS LIST
- PARTS PROGRAM PLAN
  - BASED ON SAMSO-STD 73-2 – CONTRACTUAL UPON CONTRACTOR
- PARTS PROGRAM PLAN ON SUBCONTRACTORS
  - REQUIREMENTS PASS DOWN – CONTRACTUAL UPON SUBCONTRACTORS
- CONTRACTUAL SUPPORT DOCUMENTS
  - SCREENING OUTLINES – DPA PROCEDURES
  - DERATING POLICY – LOT ASSURANCE TEST OUTLINES
- ALL PARTS SPECIFICATIONS AND PARTS PROGRAM CONTROL DOCUMENTATION REQUIRE REVIEW, APPROVAL AND ARE UNDER CONTROL OF INTEGRATED PMPCB



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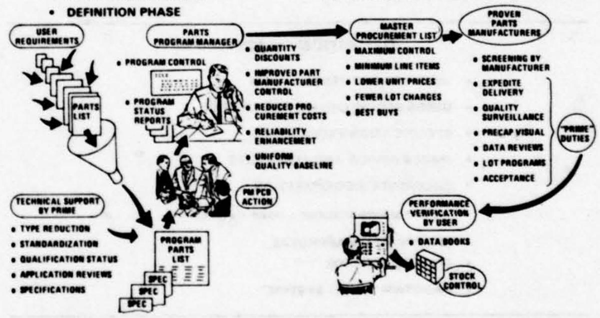
2 – DSCS III PROGRAM INTEGRATED PARTS SYSTEM (PIPS)

- PRIOR EXPERIENCE BACKGROUND
- PIPS PROGRAM SCOPE
- DEFINITION PHASE
- PROCUREMENT PHASE
- PRODUCTION AND ACCEPTANCE PHASE



PRIOR PARTS MANAGEMENT PROGRAM EXPERIENCE BACKGROUND

	PARTS MANAGEMENT PROGRAMS	TOTAL PARTS PROCESSED	YEAR
1	IRAS	40,000	1977-1979
2	SPACELAB	105,000	1976-1979
3	NIMBUS G - UPPPS	120,000	1976-1978
4	MAROTS	35,000	1975-1978
5	SSU	20,000	1975-1976
6	IUE	40,000	1975-1976
7	CORSA	32,000	1975
8	METEOSAT	10,000	1974-1975
9	HVPS - ECS	30,000	1974-1975
10	SKYNET III	80,000	1973-1974
11	OTS P.S./LOCAL OSC	90,000	1974-1975
12	ISS	30,000	1974
13	HAS	25,000	1974
14	ANS	40,000	1973

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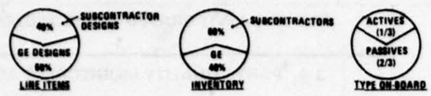
PIPS PROGRAM SCOPE

- USER IDENTIFIES PARTS NEEDS TO PRIME CONTRACTOR
- PRIME CONTRACTOR CONSOLIDATES, STANDARDIZES AND INTEGRATES REQUIREMENTS WITH USERS
- PRIME CONTRACTOR SPECIFIES, ORDERS, EXPEDITES AND DELIVERS ALL COMMON USAGE PARTS FOR 13 SUBCONTRACTORS MAKING 19 DIFFERENT PRODUCTS, IN ADDITION TO PARTS NEEDED BY PRIME FOR HIS DESIGNS



- SIGNIFICANT COST REDUCTIONS
  - UNIT COSTS LESS
  - FEWER LOT CHARGES
  - ELIMINATION OF DUPLICATE LABOR EFFORTS
  - REDUCTION OF TRAVEL AND LIVING COSTS
- UNIFORM QUALITY PROGRAM
  - COMMON PROCESS REVIEWS AND SURVEYS
  - FEWER SOURCES OF SUPPLY
  - GREATER TRACEABILITY OF DATA
- SCHEDULE MAINTENANCE
  - TIMELY ORDERING
  - PROGRAM MANAGEMENT VISIBILITY
  - PROBLEM RESOLUTION AND WORKAROUNDS

DEFINITION PHASE

- USER REQUIREMENTS REVIEW
- USERS REQUIREMENTS INTEGRATION
- SPECIFICATION PREPARATION
- PMPCB REVIEW AND COMMENTS
- COMMENTS INCORPORATION
  - PART MANUFACTURER – USER – PMPCB
- SPECIFICATION APPROVAL
- CHANGE CONTROL
- PROGRAM "ALERT SYSTEM"

PROCUREMENT PHASE

- APPROVED SOURCES OF SUPPLY IDENTIFIED (PREVIOUSLY SURVEYED)
  - VENDOR RATING SYSTEM RECORDS REVIEWED
- PART MANUFACTURER(S) REVIEWS SPECIFICATION, QUALITY REQUIREMENTS AND DELIVERY REQUIREMENTS
- QUOTATIONS PROVIDED
  - OPTIONS AND DEVIATIONS NOTED
- NEGOTIATIONS CONDUCTED
  - REQUIREMENTS SATISFACTION
  - DELIVERY
  - COST
- USER AGREEMENT AND PMPCB APPROVALS REQUIRED ON ANY DEVIATIONS
- ORDERS PLACED
- ORDERS EXPEDITED
- TECHNICAL SUPPORT PROVIDED BY PRIME

PRODUCTION AND ACCEPTANCE PHASE

- GE REVIEW OF SEM ON ACTIVES
- 100% PRECAP VISUAL ON ACTIVES AND DESIGNATED PASSIVES BY GE (CSI) AND GOVERNMENT (GSI)
- PROCESS REVIEWS AND AUDITS DURING PRODUCTION
- SCREENING AND BURN-IN PERFORMED TO GE APPROVED SCREENING PLANS
- EARLY DPA AND RADIATION TEST PROGRAMS
- TEST WITNESSING ON CRITICAL DEVICES
- PART MANUFACTURER'S DATA REVIEWS ON RECEIPT OF PARTS
- USER INSPECTION AND PARAMETER TESTS AND DATA REVIEWS
- PRIME CONTRACTOR RESPONSIBLE FOR LOT TEST PROGRAMS
  - DPA – RADIATION – LAT

GENERAL ELECTRIC'S APPLICATION OF THESE THREE KEY CONCEPTS TO THE DSCS III PROGRAM

1 – HIGHEST RELIABILITY PART USAGE

2 – PROGRAM INTEGRATED PARTS SYSTEM (PIPS)

3 – PARTS QUALITY MONITORING ACTIVITIES

3 – PARTS QUALITY MONITORING ACTIVITIES

- PRE-AWARD SURVEYS
- PRECAP VISUAL INSPECTIONS
- LOT ACCEPTANCE TEST PROGRAMS
- USER RECEIVING INSPECTIONS AND TESTS

PRECAP VISUAL INSPECTIONS – HOW EFFECTIVE IS CSI?

PART TYPE	NUMBER OF LOTS	NO. OF PARTS ACCEPTED BY MANUFACTURER	GE PRECAP INSPECTION RESULTS (CSI)		
			NO. OF PARTS ACCEPTED	NO. OF PARTS REJECTED	PERCENT OF REJECTIONS
DIODES	75	50,450	50,081	370	0.75
IC'S	273	77,732	75,436	2,296	2.95
TRANSISTORS	75	21,695	21,279	416	1.90
TOTAL ACTIVES	423	149,886	146,796	3,090	2.06 AVG.
CAPACITORS	19	2,223	2,190	33	1.48
CRYSTALS	4	12	11	1	8.33
FILTERS	7	2,243	2,228	15	0.67
RELAYS	13	1,855	1,830	25	1.35
TOTAL PASSIVES	43	6,333	6,259	74	1.17 AVG.
GRAND TOTALS	466	156,219	153,055	3,164	2.02 AVG.

LOT ACCEPTANCE PROGRAMS

- SCANNING ELECTRON MICROSCOPE (SEM) EVALUATIONS OF WAFERS
  - INTEGRATED CIRCUITS
  - METALLIZATION OVER OXIDE STEPS
- LOT ASSURANCE TESTS
  - LONG TERM BURN-IN STABILITY
- RADIATION SCREENING
  - LOT SAMPLE TESTS
  - LATCH-UP TESTS
- DESTRUCTIVE PHYSICAL ANALYSIS (DPA)
  - EARLY
  - FINAL
- PERCENT DEFECTIVE ALLOWABLE (PDA)
  - "TREAT WITH CAUTION"

USER RECEIVING INSPECTIONS AND TESTS OF PARTS – HOW EFFECTIVE IS THIS POLICY?

YEAR	QUANTITY PROCESSED	QUANTITY REJECTED	PERCENT OF RECEIPTS REJECTED
1978 (1st QTR)	162,751	3,015	1.85
1977	372,473	16,791	4.51
1976	270,106	20,258	7.50
1975	442,144	19,587	4.43
1974	1,023,891	22,628	2.21
1973	447,445	46,937	10.49
1972	273,940	18,364	6.70
1971	281,806	19,811	7.03
1970	281,958	14,690	5.21
EIGHT AND ONE QUARTER YEAR PERIOD	3,556,514	182,071	5.12 AVERAGE

DPA CANDIDATES

ACTIVES

- DIODES
- IC'S
- HYBRIDS
- TRANSISTORS

PASSIVES

- CERAMIC CAPACITORS
- FILTERS
- CRYSTALS
- RELAYS

RESULTS TO DATE (422 LOTS)

- APPROXIMATELY 2% OF LOTS ARE DISQUALIFIED BASED ON DPA RESULTS
- CURRENT "BAD GUYS" ARE:
  - CERAMIC CAPACITORS
  - RELAYS

CONCLUSIONS

- PARTS HERITAGE IS AN IMPORTANT SELECTION FACTOR
  - QUALIFIED – CONSISTENT SOURCE – GOOD USAGE RECORD
- THE BEST TYPE OF PART TO USE FOR A LONG-LIFE MISSION IS THE HIGHEST RELIABILITY AVAILABLE
- QUALITY MUST BE DESIGNED INTO A PART; IT IS NOT A PRODUCT OF SCREENING
- A WELL MANAGED, COORDINATED PROCUREMENT PROGRAM OFFERS COST, QUALITY AND SCHEDULE ADVANTAGES
- PRECAP VISUAL INSPECTIONS (CSI) ARE A VERY IMPORTANT PRODUCT QUALITY TOOLGATE DURING PRODUCTION
- DPA IS AN EFFECTIVE TOOL TO FIND POTENTIALLY MARGINAL UNITS
- USER RECEIVING INSPECTIONS AND TESTS ON PARTS IS A VERY VALUABLE FINAL CHECKPOINT
- PARTS MANAGEMENT IS TRULY A "WOMB TO TOMB" CYCLE

NASA STANDARD PARTS PROGRAM

Joseph L. Murphy
Manager, Parts and Material,
Program Assurance Division

Established to Deal With:

- Small quantity buys
- Reliability demands vs. high cost
- Multiple specifications
- Duplicative engineering efforts
- Long delivery schedules
- Market influence and fluctuation
- Failures and expensive rework

Purpose

- Increase availability of reliable microcircuits, transistors, diodes, capacitors and resistors
- Reduce overall costs -- eliminate duplication

Applicability

- In-house and contracted work

Scope

- New programs -- flight hardware and mission essential
- Ground support equipment

NASA Events

Leading to Joint Parts Program

1964	NPSC Microelectronics Subcommittee
1972	Microelectronics Reliability Program
	NASA/DoD Agreement
1974	NASA Std Parts Program
1975-76	NASA/SAMSO coordination started (space parts working group)
1977	NASA/SAMSO activities accelerated
1978	Joint requirements being implemented

Joint SAMSO/NASA Parts Approach

- Develop Class "S" (space quality) requirements
  - Microcircuits
  - Diodes/transistors
  - Hybrids
  - Other devices
- Incorporate Class "S" into mil specs
- Develop Class "S" certification requirements
- SAMSO/NASA/DESC certifications
  - Eliminate audit duplication and overlap
  - Reduce audit expense
  - Improve uniformity of audits
- Class "S" qualifications
- SAMSO/NASA preferred parts list
  - Procurement volume

Accomplishments

- NASA-SAMSO agreements on Class S
- Revised MIL-STD-975 (std parts list)
- Issued MIL-STD-976 (certification)
- Certification guidelines issued - DESC-EQE-44
- SAMSO/NASA/DESC operating procedure signed
- Conversion of Class A to S and new certification started
- MIL-M-38510 and MIL-STD-883 revised/issued
- MIL-S-19500 and MIL-STD-750 revised/issued
- Detail specifications initiated - 38510, 19500
- ER specification study initiated

NASA Standard Parts List

MIL-STD-975 - released Jan 1976/revised Aug 1977

Covers - microcircuits - MIL-M-38510

Transistors Diodes	MIL-S-19500
Capacitors Resistors	"ER" Spec

Includes - two quality grades

Quality Grades

	Grade I	Grade II
Microcircuits	Class S	Class B
Semiconductors	JAN S	JAN TX
Resistors Capacitors	"S" (0.001%/ 1000 hrs)	"P" (0.1%/ 1000 hrs)

Application of Quality Grades

NASA Shuttle Instrument Classes	Payload Category	Quality Grades
"A" Maximum Confidence	Upper Stage	1
	Planetary, deep space, geosynchronous	
	Directly deployed	1 and 2
	Earth applications, science	
	Attached experiments	1 and 2
	Scheduled or critical objectives	
"B" Normal Confidence	Upper stage	1 and 2
	Directly deployed	2
	Attached experiments	Total Range of Available Parts
	Space Available	

Activity Expansion

Hybrids	Thermisters
Connectors	Transformers
Filters	Crystals
Fuses	Inductors
Relays	Wire and Cable

NASA Program/Project Benefits

- Supports payload policy
- Easily understood baseline for design standardization allows cost estimates from experience
- Two quality grades of parts - more reliability experience
- Lower project engineering costs
  - Fewer specifications to prepare and coordinate
  - Fewer qualification tests
- Lower part procurement costs
  - Larger nationwide usage of same parts - joint NASA, SAMSO requirements
  - Class S microcircuits 15% lower than MSFC preferred
  - Suppliers familiar with specifications - larger cost amortization base
  - Parts stocked by suppliers or shorter delivery
- Center parts specialists can devote more time and attention to nonstandard parts
- Provides standardized baseline for project common procurement (larger volume)

Benefits of Project Parts Consolidated Procurement

- Lower unit costs
- One central procurement contract - eliminates redundant cost associated with multi-tiered procurements
- Shorter delivery times
- Full technical control at program level of parts quality and reliability
- Leverage of high volume purchasing

NASA-Wide Consolidated Procurement Study - Estimated Results

20%	Increase (net) in NASA parts inhouse support
12%	Decrease in parts cost
37%	Reduction in contractor parts engineering support
49%	Reduction in contractor parts material overhead, G&A, profit

$35 million savings first five years of operation

$150 million savings first ten years of operation

Consolidated Procurement Experience

Viking Program

2.5 million parts - 90% delivered to 18 contractors in less than a year

100,000 Class A digital microcircuits - 90% of order and 100% of line items delivered in 10 months

Estimated savings $20 million

HEAO-"A"

Parts valued at $1.1 million

Estimated savings - 10% to 20%

Lead time shortened by 4 to 6 months

RFP bid cycle was shortened by 30 days

Results - HEAO "A" passed 8 month performance period on April 12, 1978 without any known electrical part failure

Where Do We Go From Here

- Promote standard parts use
  - NASA - Grades 1 and 2
  - SAMSO - Class S
- Accelerate Class S qualifications
- Continue to review and develop detail specifications
- Develop other Class S part types
- Promote contractor parts consolidated procurement
- Continue and expand dialogue and coordination
  - User agencies
  - Manufacturers
  - System contractors
- Improved packages, materials, processes

DESIGN PANEL

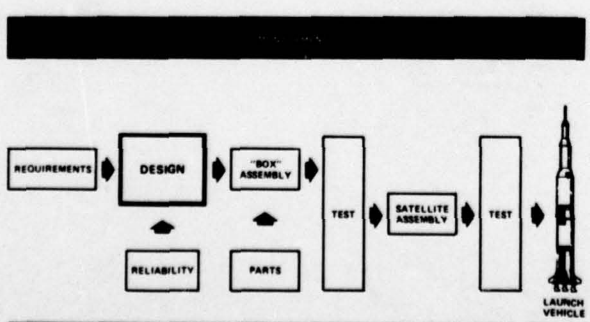
Mr. Paul E. Wright, Moderator
Vice President, Engineering
Government Systems Division
RCA Corporation

This Panel will deal with the subject of designing for mission assurance. As you can see from the list of names shown on the viewgraph, we are fortunate to have a distinguished group of senior executives from the Aerospace Industry. This Panel brings well over 100 years of technical and management experience to the subject. The majority of successful space missions in this country since the beginning of the space era have, in one way or another, been touched by the members of this Panel. I am, therefore, pleased and honored to introduce them to you.

As the block diagram indicates, design is one of many steps in the process linking requirements with the launch of a spacecraft. Our concern is with mission assurance. Mission Assurance clearly extends beyond the date of launch; indeed it extends to the end of satellite life. But to a first approximation, the controllable variables in mission assurance are those shown in this block diagram. The next diagram lists a few of the elements of designing, as that word is used in the context of today's meeting. An important issue for the spacecraft design team is the balance of performance against protection. In other words, it is the trade-off of high performance against an insurance policy for success of the spacecraft. Another important issue that will be dealt with by the members of this Panel is the question of testing – where should it be done, how extensively should it be done and how can one design the spacecraft to facilitate appropriate and comprehensive testing. Clearly, both government and industry share in the responsibility for designing for mission assurance. The generation of specifications and requirements by the Government strongly influence the degree to which industry can successfully design for mission assurance. Another design issue is the matter of hardware/software tradeoff because of the rapid maturity of computers implemented in LSI and, even more pointedly, because of the advent of the microprocessor and the ability to distribute computational horsepower throughout the spacecraft. Careful modeling of the design before it is finalized is also important to mission assurance.

Our most important overall objective in spacecraft design, given the achievement of a threshold level of performance, is to achieve high quality – quality that will insure mission success. Pursuant to that goal, traceability of the design is a part of achieving that level of quality. It is important, however, to realize that traceability is not a substitute for quality in the design process.

Program Elements



DESIGNING
For Mission Assurance

- Performance vs. Insurance
- Test Philosophy
- Government/Industry Responsibility
- Software/Hardware Trade
- Modeling
- Traceability/Quality

DESIGNING FOR MISSION ASSURANCE

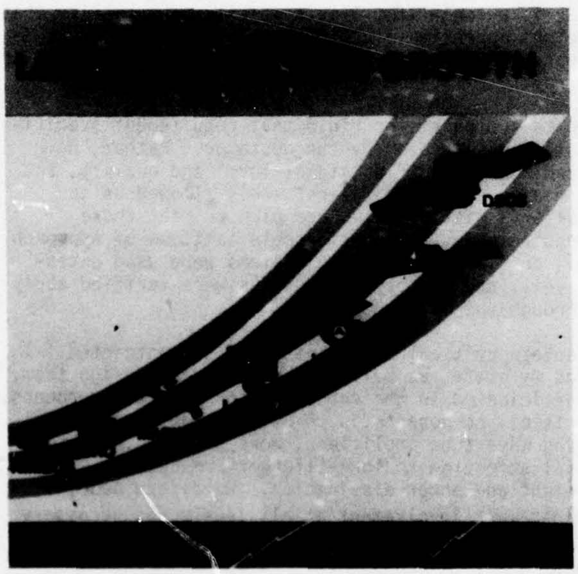
Lee L. Farnham
General Manager, Space Division
General Electric Co.

It is a pleasure to participate as a member of this panel and to share some of the experience my organization has acquired while living in the changing world of mission assurance over the past 20 years.

I have focused on the following parts of the conference's objective – examination of key elements and factors critical to space mission success, and – identification of tools, techniques, and methods to minimize and control risk.

Vu-Graph Programs

General Electric has participated in many long-life mission programs for NASA, international customers, and DOD. Some of them are shown on this vu-graph. From our experience on these programs, we have developed a spacecraft design philosophy for mission assurance. It is characterized by strong adherence to the concept of Design Verification, and the tailoring of test plans to meet the individual program's long-life mission requirements. It will have time only to outline some of the methods we have used for Design Verification, and to show you some of the tools we have developed to help us "tailor" program plans to Mission performance goals.



The majority of our early programs were applications satellite systems, such as the Nimbus program, begun in the early 1960's to provide data for atmospheric andand meteorological researchers. As a test vehicle for earth observation instruments, the program has grown in capability and performance.

Spacecraft power for the six vehicles already orbited is 575 watts, and the data rate is 800 kilobits. Total spacecraft weight has grown from 820 pounds to 2,000 pounds to accommodate growing instrumentation payloads, without substantial spacecraft structural redesign.

The program required 3-axis stabilization for precise instrument pointing, reliable command control and data communication systems, and an orbital life of from 6 months to 1 year. In service, life has ranged from 32 months for Number 2 to more than 99 months for Number 4. The last three, launched in 1970, 1972, and 1975, continue to return useful data.

Mission assurance was a rather primitive discipline in the early Nimbus days. Here is what it was like in that era:

- We had very little experience or data to guide our design effort.
- Payloads and spacecraft structures were simple, and rather small, due to the limitations of the booster systems; therefore
- We didn't have payload weight for extensive redundancy; and
- We thus had to endure high single-point failure risks.

These limitations in knowledge and experience created a heavy reliance on analysis techniques. Our customer also had limited experience, and hoped to reach his mission assurance goals by imposing rigid specifications on his contractors. But as the early programs matured and design teams gained experience, we began to develop a more flexible and tailored design process aimed at meeting mission requirements.

I'd like to trace the development of some of these techniques on successive programs.

In the beginning, as I said, we could meet the rigid specifications only by analysis. In order to verify the analysis, we conducted tests at every possible level of assembly. Naturally, this process accumulated much test data. But it did not necessarily assure mission success, since we were testing to meet a specification, without the benefit of actual long-life mission data. But it was this test data which became the base which ultimately allowed us to tailor our design approach to particular program requirements.

The Landsat Program which followed the Nimbus family of spacecraft was designed by using the experience of Nimbus. Let me briefly summarize the Landsat mission.

The Landsat program obtains earth resources information on a global repetitive basis from remote sensors in space.

The first Landsat, launched in 1972, was designed to operate for one year in a near-polar, sun-synchronous orbit 570 miles high. Actual life was 5 and 1/2 years, after which it was turned off by NASA. Landsat 2, with a design life of one year, was launched in 1975 and after three years is still operating, as is Landsat 3, launched last month.

The Landsat program has already provided a half-million images of the earth to over 100 nations, using wide-band digital data transmission systems to accommodate the high data rates necessary for

image transmission. These images provide an important input in monitoring, mapping, surveying, and estimating natural and man-made resources, such as crops, water supplies, energy sources, and geological features.

To meet mission assurance requirements for the Landsat Program, our base was the proven designs from the Nimbus family of spacecraft, and the test procedures we used to verify them. The designs include the 3-axis attitude control system, the open butterfly spacecraft configuration, and the Solar Array Paddle system.

To meet the mission requirements for new component designs, we developed and applied the concept of early all-up design verification. This concept was evolved during the early Nimbus program and progressively substantiated, for we found by experience that System-level Engineering Model tests tended to come too late in the design cycle to be fully effective. The engineering model also proved to be a poor test vehicle in the formative design stage, since the test-point access was very difficult. Also, replacement and repair work took too much time and effort because of the difficulty in disassembling and reassembling both the functional and structural components for troubleshooting and adjustment.

To appreciate these difficulties, look at this Engineering Model of an early Nimbus Spacecraft being checked during systems test. Since assembly normally happens very late in the design cycle, there is no provision for rapid trouble shooting and easy rework, which are so necessary during early tests for design verification of the overall system.

Contrast this with the technique we now use for early system design verification. We call it the Bench Integration Test or "BIT" system. This approach allows an early all-up system test. The components are laid out on a specially configured bench that allows easy access to components throughout the system. We have tailored the system test program specifications to allow the use of the BIT approach. We gain early verification of system

design performance and create the opportunity to make an intelligent assessment of the degree of subsequent system testing required.

Bench Integration Test is designed for ease of trouble-shooting and rework. The test procedures, the interfaces with the ground support equipment, and software associated with the system are important products of the BIT system, since we maintain full test procedure discipline on all these elements. This discipline carries through the assurance of test readiness for the all-important flight spacecraft.

The experience we gained in the Earth Observatory Spacecraft has proved to be very valuable when applied to a communications satellite program called BSE.

BSE, the Medium-scale Broadcast Satellite for Experimental Purpose, was designed by General Electric under a contract to Toshiba for the National Space Development Agency (NASDA) of Japan. The spacecraft was successfully launched on April 7 into a geosynchronous orbit where it will be used for experimental color television and voice transmission over two channels to small ground receivers in remote and urban areas of Japan. These experiments will be carried out over a 3-year period to test the effect of atmospheric and geographic characteristics on the Ku-Band uplink and downlink satellite signal transmission.

BSE is a long-life, 3-axis stabilized satellite that weighs approximately 1500 pounds and can produce nearly 1 kilowatt of power from a sun-oriented solar array.

On this program, no rigid test requirement specification was imposed by the customer. Rather, he required a specified signal level and quality, and a mission life of 3 years. This allowed us to tailor a Mission Assurance plan to meet those requirements, and considerable latitude of approach was possible. Proven subsystems were used extensively, and new payload designs were verified early through the BIT process.

Certain critical components were subcontracted. I and my staff, as well as the cognizant design team, participated in the subcontractor selection process. Critical components, such as the high-power travelling wave tube amplifiers, were selected with special attention to long-life performance, as well as weight and power dissipation. We determined that management involvement at all levels was necessary to assure that critical components from subcontractors would meet the severe long-life requirement. This level of management involvement obtained the needed business commitment from each of the major subcontractors to meet the three-year design requirement.

Another management technique which grew out of Nimbus and Landsat experience was very successfully applied on BSE.

We call it the EMQ Design team approach. The "E" designates the engineer responsible for the design of the component; the "M" identifies the manufacturing specialist whose responsibility is producibility; "Q" is for the Quality engineer, responsible for the controls on parts, materials, and processes,

as well as for the testability of the component under design. These teams are formed at the beginning of the design phase and provide early integration of the disciplines, so necessary for the ultimate performance of a newly designed product. It is this team that is "in the trenches" to prevent potential single-point failures and properly analyze failure reports. It is this team that answers the following questions during the early design period:

- Does the design meet the requirements?
- Is it producible?
- Can it be verified by test?

We feel that design verification is so important that we include it as an agenda item on all design reviews. As I mentioned earlier, the all-up BIT process also provides an early verification method for the ground support equipment, software, and test procedures associated with the flight spacecraft.

Working together, the EMQ team and the BIT method provide a design that can be verified at the earliest possible time in the design cycle and at the most logical level of the spacecraft assembly.

An adjunct to this technique is the identification and emplacement of the skills needed to manufacture and test the components requiring the use of new parts, materials, and processes. This technique is called Process Readiness, and it functions under a rather rigorous plan which includes management discipline.

The slide shows the steps by which a process readiness plan is generated. It begins with a review, under the scrutiny of my management team, to determine if the new process is needed. It concludes with a letter to the General Manager which certifies that the process meets the criteria established by the management review team. You can see the signed specimen letters on the slide by which my managers literally put their professional reputations on the line, in writing, to guarantee that all risk and problems have been removed from any required processes.

No new critical process is approved for use unless the managers of Engineering, Manufacturing, and Quality certify in writing as you see on the vugraph. I consider this management involvement the cornerstone in the certification of Readiness for every new Process.

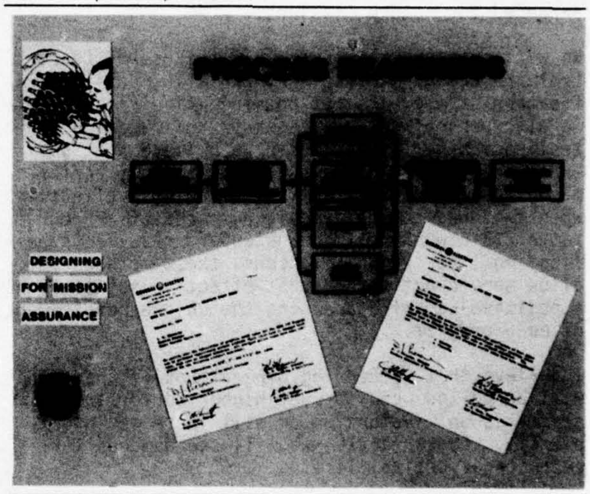
We are now applying these techniques to a program which has the most demanding requirement for mission assurance. It is called DSCS III.

The DSCS III Communication Satellite program will help meet national military communications needs of the 1980's. It will operate at synchronous altitudes with total RF output power of 120 watts through 6 channels. The RF can be switched through multiple transmit and receive antennas to provide coverage patterns ranging from the whole earth to narrow spot beams. Operational versatility is achieved through two, 19-beam waveguide lens transmit antennas and a 61-beam waveguide lens receive antenna.

The telemetry command and control subsystem interfaces with multiple ground-based terminals and is capable of providing rapid configuration of both transmit and receive multi-beam antennas. The spacecraft is 3-axis stabilized with a 10-year design life. Latest developments in hardening are being used to insure reliability.

In operational use, a constellation of 4 satellites will be placed in orbit over the Atlantic, East and West Pacific, and the Indian Ocean.

I'll have time for only a brief summary of the mission assurance tools and techniques being used on this program. With the combined requirement of 10-year mission life and radiation hardening, the greatest impact on mission assurance was determined to be at the piece-part level. This determination has dramatically affected the procurement specification of piece parts.



This vu-graph shows how the type of specification for active parts evolved as the mission life requirement increased from 1 year to 10 years. For example, in the 1960 time period, the military JAN types were acceptable for the mission life up to 1 year. Next, the JAN TX line demanded parts that were screened and burned in. It was followed by JAN TXV which, in addition, required "pre-cap" visual Inspection on semiconductors as a tollgate to minimize workmanship and contamination defects. These provided parts specification meeting mission life requirements of up to 3 years.

The next line of parts specification is referred to as Class A type, which requires parts to be examined by the Scanning Electron Microscope as well as other tests. This parts specification is for mission life up to 5 years.

At present, Industry and Government are in the early stages of developing a Class "S" parts line for integrated circuits which require additional controls and certification of processes. However, the availability of Class "S" parts specifications is limited and, therefore, we at General Electric have generated our own Class "S" specification, called an "R" drawing, for various integrated circuits, transistors, and diodes.

Our experience has also shown us that stress testing at all levels is essential, with the highest stress applied at the piece-part level. We believe that this method will provide the high reliability parts required to meet the DSCS III 10-year mission.

In this way, we constantly impose new and more stringent requirements on parts and materials to meet hardening and reliability requirements. But that is not enough. Additionally, we need redundant subsystems, and these require additional weight and power, imposing new economies on the designer. For these economies, we use hybrid technology extensively. The net result is a spacecraft having a tremendous number of piece parts and redundant critical components. We can tolerate this design principle only because we have high confidence that we have isolated the risk at the piece-part level, and that our stringent piece-parts test program will give us the necessary mission assurance.

It is very clear to us that the approaches outlined and followed on our previous programs must be expanded for future missions.

We will continue to use the BIT philosophy to control the design process. By achieving design verification at the earliest possible time in the cycle, we also prevent the unnecessary proliferation of testing farther downstream. We believe that our experience in achieving successful flight performance has shown that testing can be more effective when tailored to the individual needs of a program rather than working from a standard baseline specification. For future missions, these methods may allow more creative and cost-effective solutions as a positive way of addressing the unique requirements of each program.

I believe that succeeding generations of spacecraft will be called upon to meet higher performance standards on missions which will increase in complexity. Concurrently, we will see demands for even longer orbital life.

This will impose two requirements on the designer. First, he must establish a family of piece-part specifications and selection processes which enable him to match his assurance level to the demands of each mission; and second, on this foundation he must erect a system structure which will verify his designs from top down early in the design process.

At General Electric our Mission Assurance plan is built on these assumptions and operates through five basic principles:

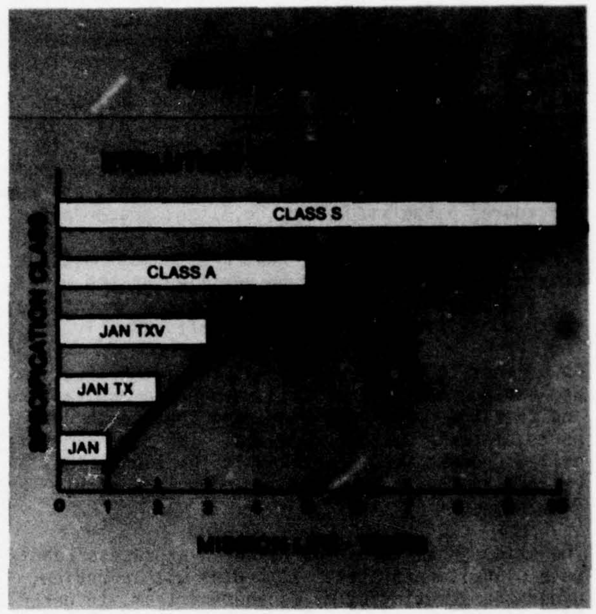
First, we believe in earliest possible all-up system integration testing because we have learned that this is the effective and most economical level at which to discover and remedy system-oriented problems.

Second, we exert constant pressure on piece-part qualification and selection, driving our test regimes steadily downward to the most elemental level in order to meet the challenges of constantly increasing mission life.

Third, we believe that the EMQ team design process on each component should incorporate necessary standards for producibility and testability. There is no place in the modern design cycle for procedures which attempt to inject these elements after the fact.

Fourth, an effective Mission Assurance program demands not only Management oversight, but Management involvement. This will assure that the level of Management attention is commensurate with the mission risk involved at each stage of the design and development process.

Fifth, there must be a constant search for innovation and flexibility in both design and test principles. The designing organization must be given every opportunity to apply its experience and ingenuity to produce the largest Mission Assurance increment at the lowest possible cost.



THE ROLE OF TESTING IN DESIGNING FOR MISSION ASSURANCE

Richard R. Fidler

Key Words: Mission Success, System Test Bed, Design Objectives, Prototype, Entity, Subsystem

Abstract

Adequate testing is one of the key elements in meeting Mission Assurance Requirements. The Government and the contractor must give more emphasis to the role of testing. All test elements must recognize the importance of Mission Assurance. Normal development testing and operational testing is not sufficient. A total System Test Bed is necessary to assure performance.

Introduction

I have chosen to focus my remarks on the Role of Testing in Designing for Mission Assurance. However, before I get to the main theme, there are several comments I would like to make. I want to touch on the contractors' role, and the importance of the Government's role.

As a contractor, we face the problem of balancing Performance, Cost and Schedule. But we are not autonomous – the Government must structure a program compatible with an appropriate balance, must communicate their requirements, and must be party to the decisions necessary to maintain the balance.

I cannot emphasize too heavily the importance of a clear understanding of the total program requirements. While the contract specification must be the baseline, these documents can only scratch the surface in conveying the entire picture. Other contract communications, such as contract incentives, often reflect on the implementation of the program in such a fashion that Mission Assurance is weakened. Too often, recently, contract incentives have not been properly used as a tool for establishing the relative importance of requirements (performance, schedule and cost). It results in motivating the contractor to maximize his profit, often to the detriment of the program. More emphasis must be placed on balancing the program objectives by rewarding the contractor for meeting the mission performance requirements.

Mission Assurance is not a separable requirement: It is an essential part of the performance requirements. Its role must be recognized in structuring the program. Adequate allowance must be made in the schedule and in the costs to assure mission success. Adequate testing is one of the key design elements that has a significant influence on meeting the Mission Assurance requirements, and on total cost and schedule impact. Thus, we (the Government and the Contractor jointly) need better balancing of performance, cost and schedules tied into the testing function for Mission Assurance attainment.

The Importance of Testing for Mission Success

A strategic weapon system must be capable of meeting all of its operational requirements under actual field conditions and, in many cases, this may mean sitting in the readiness mode forever. Testing is one of the design tools necessary to assure that it will do the job, if needed. Unfortunately, in today's world, the emphasis in electronics is more and more on careful design, analysis and review, to the detriment of testing. GTE Sylvania's successful experience indicates that there is no substitute for adequate testing to assure Mission Success. Now let us examine this broad subject – Testing.

The Winter 1977 Defense Systems Management Review was devoted to test and evaluation. Many of the contributors discussed testing to assure hardware reliability. The role of testing to provide Mission Assurance testing on a systems level was hardly mentioned. One contributor to the Defense Systems Management Review defines the primary responsibilities of development test as answering the two questions:

1. "Does the system meet the engineering specifications? and,

2. Is the system sufficiently developed to enter production?"

The same author says:

"Operational test and evaluation issues are:

a. Does the system operate effectively in its intended operational environment? and,

b. Can "blue-suit" personnel maintain the system as envisioned in the maintenance concept?"[1]

Neither the development test objectives nor the operational test objectives include the total system tests to assure mission success.

Another contributor lists his goals as:

"• Shorter tests.

• Schedules where efforts can be combined and outlays reduced.

• Ways testers can work with industry and developers to further reduce expenditures."[2]

While these are fine goals, how about – better assurance of mission success? I advocate it is more technically sound, cheaper, and faster to solve the Mission Assurance design problems during the initial design/development program, utilizing a total test program than to discover these design anomalies during the complex field test programs or under operational use.

Identifying the Tests

What are some of these design tests that are key to supplying Mission Assurance?

Engineering Breadboard Tests

These are the earliest design tests necessary to support the design of the equipment and ferret out inherent design problems. They should not be overly structured, but it is important that they be sufficiently documented to provide a basis for review and understanding by others.

Engineering Development Tests

Functional elements of the system should be tested before the system design is truly frozen – it is in these tests that operational anomalies not covered by the specifications are first identified: i.e., is there an unexpected harmonic content? This data must then be fed into the system design to assure that no degradation of performance will result.

Prototype Tests

Prototype tests confirm the design and assure that the final manufactured units will perform in accordance with the design objectives. Prototype tests should be conducted at all levels:

a. Components – Components must be tested at two levels; they must be tested to verify their performance under the expected application, and they must be tested to assure their inherent quality. The second requirement is the normal quality control function. Component testing is returning to its proper balance.

b. Assemblies and Subassemblies – You will find many programs that get into difficulties have short-changed this design step. Prototype assemblies and subassemblies should be returned to the engineers to verify that these units work like the breadboard. Here is where problems with ground loops, stray coupling, and thermal problems really surface. Many of these will have been avoided if the breadboard tests are thorough, but this is the place to catch the rest of them before the production run.

Functional Entity Tests

Most systems are subsystems made up of major functional entities. In our case, these are usually Contractor End-Items and constitute a single rack of equipment. These have a complete Government procurement specification and should be tested against their specification. In addition to the functional requirements, this is the level at which environmental and quality tests can be performed most economically. Unfortunately, the pressures of schedule and costs often delay the performance of the complete qualification tests. For this reason, it is imperative that as much data as possible be obtained on environmental problems earlier in the design program, utilizing an engineering test program, especially if the formal qualification test program has been eliminated or delayed into the production phase.

Subsystem Test

The highest level for which the individual contractors are usually responsible is the subsystem testing. Too often it is assumed that stringest testing at the Customer End-Item level is an adequate substitute for a thorough subsystem test. When the pressure from cost and schedule builds, it results in pressures to reduce or eliminate the subsystem testing. If a high confidence in the Mission Success is to be achieved, the subsystem must be tested far beyond those tests necessary to confirm compliance with the stated normal system operational requirements. There must be tests to confirm all operational uses of every part of the system, especially those uses or modes which occur only occasionally in pre-attack normal operations, but are critical during post-attack operations. The identification of the parameters to be measured is in fact a significant design task. The failure mode and effect analysis provides a guide in determining key parameters, but properly designed testing is a specialty unto itself.

The tests must be designed to detect every anomaly and must capture the data to pinpoint the cause. Mission Assurance can be achieved only if the anomalies are identified, and the root cause determined. Only after the cause is identified can appropriate corrective action be taken. I don't mean to imply that every unexpected event is wrong – often it may be normal and no further action will be necessary; however, this decision can be made only after the root cause is understood. The subsystem test program must provide also the flexibility for special tests where unexpected events dictate a need. It is alarming how many major programs have inadequate subsystem test programs!

System Test

Everything that can be said about subsystem testing can equally be said for total system testing – and more so! In today's digital world, the complexity of the interfaces has mushroomed. . . we see one contractor's computer controlling another contractor's hardware, perhaps with a third contractor's software residing in the computer. Simulators are not the answer! A complete system using the real equipment is the best guarantee of performance! For most major systems, it is more cost and schedule-effective to perform the initial system tests program at the contractor's design facility, rather than totally performing system tests at the Field Sites.

Significant Elements of a Proper System Test

The significant elements of a proper system test are:

1. All equipment must be as close to the final hardware configuration as possible. A good test bed will contain the complete suite of operational hardware. All means ALL and it includes:

   - Operational Cabling
   - Operational Environmental Control
   - Operational Power Systems
   - Representative Radio Links
   - Representative Cable Links
   - A Source of Representative Traffic

2. The Test Bed must be as close to the final operational equipment layout as is possible. Many more problems are associated with physical layout than are normally

recognized by those who are functionally oriented. Only with a good mechanical simulation will you be able to identify:

- Clearance problems - It can cost more to change from a straight-thru connector to a right-angle connector than it costs to modify a card.
- Thermal problems
- Cable lengths
- Human factors
- Maintenance and access
- Operator abuse - (Yes, we have had to correct a critical problem because the operator's chair slammed into the console.)

3. Strict Configuration Control is a <u>must</u>. This statement has to be applied to both software and hardware.
4. Test documentation must be complete.
5. The Systems Engineers must prepare Test Requirements which must encompass 100 percent of the Mission Operational requirements.
6. The test operation should be independent of the design groups. Their job is to gather the data and define the results, not to continue the design or to rationalize away the results as not important.
7. Adequate design and system engineering support from all Associate Contractors must be available. While it is the role of the test operators to run the tests, the designers are in the best position to recognize the significance of any indications and correct deficiencies in the tests on the spot.
8. Fast accurate, feedback of results to ALL. Along with this goes the responsibility of the contractors to review the results and take action.
9. A representative of the procuring agency must be a part of the test team. The operation of test programs requires many decisions which are outside the responsibility of the test operator, priorities must be changed, an equipment malfunction may preclude running a test, or mean a modification to the test plan. Schedule slips may impact on plans, and support to a high priority problem may throw everything into a cocked hat.

This type of initial System Test Program often gets the first axe by many Government SPOs and/or contractors because of the design costs and schedules, even if it is realized that it will take greater time and dollars later to resolve the anomalies.

Does This Test Design Tool Work?

Our experience indicates it is a huge success if planned, budgeted and implemented under the same management and customer leadership that all technical and contractual requirements are directed. We applied this approach to the Minuteman Weapon System. For the WS-133B Minuteman System Development Contract, the Government had balanced incentives for performance, test, schedule and cost items. Thus GTE Sylvania, as the design, development, build and test contractor, was able to establish its own proven, cost-effective design/test balanced program, including a System Test Bed.

A configured launch facility and a configured launch control facility were established in nearby Waltham, Massachusetts and a second launch control facility was established locally in West Roxbury to provide a radio link as part of the total test configuration. System testing started in 1963. After its initial basic use, this System Design Test Bed was successfully utilized to support the 1965-1967 VAFB firings and the Operational Deployment during 1965-1967. Additionally, it has been used from 1969 until now for resolving design modifications for three major weapon system additives (UHF, Hardness and Command Data Buffer). The responsibility for System Testing is now being transitioned to OALC at Hill Air Force Base. The equipment from the GTE Sylvania Test Beds is being used to establish the HETF-II Test Bed there.

It is difficult to prioritize the many uses these test beds have served. The emphasis has changed as the system has matured. The mission of the test bed was defined as:

- Demonstrate that integrated equipment and software meet the Weapon System requirement.
- Identify design problems early, thereby permitting least-costly correction.
- Duplicate field problems and verify recommended solutions.
- Provide a test vehicle for kit-proofing.
- Test improvements to the system.

Did the test program fulfill its mission?

Let's look at a few statistics (for the initial WS-133B System):

794 problems were identified by testing the integrated system.

265 of these results in GTE Sylvania ECPs.

Because of the early identification of these problems, 65 percent of the ECP changes were incorporated in line production prior to fielding of the operational sites.

If the ECPs had required field retrofit, the cost would have been an additional $20 million. The cost for running the test beds during this period was $5 million. A net saving to the Government of $15 million — and this is only the saving on the GTE Sylvania equipment; similar benefits were derived by the other associates. Of even greater significance no missile launches were delayed or failed because of a ground launch failure. Total Mission Success!

I want to emphasize with an example that the function of a test bed goes far beyond hard dollar savings and the hard failures of hardware. During our system testing at Waltham, a critical loss of system synchronization was identified. This was a subtle problem that occurs only when the system is in a partially "down" state. That is a key – in normal operation, the problem does not exist. Operational testing would not have identified it. Testing at Vandenberg failed to identify it. A special team was established with representatives from GTE Sylvania, Autonetics, Univac and TRW. It was determined that a hardware interrupt in the Weapon System Computer was at fault and a Univac ECP resulted. This type of system capability exists only at a system test bed and must be an integrated part of assuring Mission Success.

In summary, I would like to emphasize the following points:

- The Government and the Contractors must give more recognition to the role of testing.
- Adequate testing means testing at all levels.
- Testing should include the entire system.
- Testing is cost-effective.
- Testing is necessary to assure performance throughout the life of a program.
- Adequate testing is a key element in designing for Mission Assurance.

References

[1] "Improving Air Force Independent Operational Testing", Defense Systems Management Review, Vol. 1, No. 5 (Winter 1977), pg. 21.

[2] "Streamlining Army Testing", Defense Systems Management Review, Vol. 1, No. 5 (Winter 1977), pgs. 7 and 8.

Biography

Mailing address:
Richard R. Fidler
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Mr. Fidler is the Vice President and General Manager of the Communication Systems Division of GTE Sylvania. Major programs in this division include the Minuteman Ground Electronics System, Minuteman Launch Facility Lithium Batteries, Seafarer, Navy and DCA Telecommunication programs, and Survivability/Vulnerability programs for the Air Force and DNA.

Previous positions he has held include: Program Manager of the Minuteman Ground Electronic Systems, Director of Engineering of the Eastern Division of GTE Sylvania, and Manager of the Advanced Systems Laboratory and the Data Conversion Laboratory.

Mr. Fidler received a degree in Physics from Gettysburg College and ho-ds a Masters degree in Electrical Engineering from M.I.T.

DESIGN FOR MISSION ASSURANCE

Robert W. Hager
DIVISION MANAGER, SMSD, BOEING CO.

The success of a space mission is primarily established during the design phase of the program. Although subsequent activities in procurement, manufacturing and testing are critical and can impact mission success if not properly conducted, there is no way to build back in reliability if it doesn't exist in the basic design. Therefore, achieving mission success must be a primary design goal.

There are a number of design techniques which can significantly improve the mission success. These include; (1) more emphasis on parallel operating redundancy. That is, redundancy without switching to a standby system; (2) use of a conservative electronic part de-rating criteria; (3) have the designer directly involved in the failure mode and effect analysis; (4) eliminate single points from the design as far as possible and rigidly control those which cannot be eliminated; (5) utilize sneak circuit analysis to assure that there are no unknown and unwanted feedbacks in the system; and (6) specify conservative burn-in testing requirements.

All of these techniques, I'm sure, sound familiar and, to some extent, are being used in all complex designs. In the design of the Inertial Upper Stage we are using these techniques with some unique applications. I will cover some of these in more detail and show the benefit we expect to gain.

One of the more significant questions which arises in the design is how much redundancy is really cost effective. We can add more redundant elements in the system and continue to improve to some degree the calculated reliability, but with an increasing cost and weight penalty. Optimizing the system architecture is a process of balancing the cost of reliability improvements against the cost of failures to achieve minimum total cost over the lifetime of the program, as shown in Figure 1. The approach starts with a single thread system and adds reliability options. The cost of failures is evaluated for each option by multiplying the expected number of failures by the cost of replacement or repair and re-flight and then is summed with the life cycle cost of the option to obtain total program cost. This process of adding options continues until a minimum program cost point is located. There is generally a rather sharp upswing beyond this point because the life cycle costs of additional redundancy become increasingly larger and the savings in cost of failures is smaller as the mission reliability increases.

The IUS Program cost analysis model, as shown in Figure 2, is the method used to guide the design toward a cost optimized system architecture. Because of the high leverage that the IUS has on the total cost of successfully delivering spacecraft to orbit, the cost effectiveness is conducted at a level above the IUS hardware life cycle cost and includes the cost of replacing aborted or lost missions. The model is run for each reliability option. For each separate mission, the model sums the mission cost elements. It then determines the probability of an abort prior to IUS deployment from the orbiter as well as the cost of reflying the mission after refurbishment of the recovered IUS/spacecraft. It also determines the probability of an IUS mission loss after leaving the orbiter. The model processes the total 112 projected missions and sums the total cost for the particular configuration option.

The results of the cost optimization are shown in Figure 3. Starting with the single thread system with a reliability of 0.84, redundant elements were added to the system in a prioritized order of those with the largest reliability component per dollar of life cycle cost. The plot is in reality a series of point options. The cost optimum reliability was achieved with the addition of redundant drives on each of the four thrust vector control actuators. Additional redundant subsystems such as the third computer were not cost effective because the additional cost was higher than the savings in cost of probable failure. A number of additional redundant items were also evaluated and not used. The limit is the single point reliability of the solid rocket motors and the structure. In the case of the IUS, the cost optimized point exceeded the .96 reliability requirement. There may, however, be other programs where this type of analysis would show an optimum point below a pre-selected reliability requirement. In that case, the reliability requirement should be re-evaluated. The results of this method are relatively insensitive to the cost of the spacecraft. For example, a 50% increase in spacecraft cost would increase the program costs by only 1.3%. Very conservative estimates of the reliability for individual elements derived from MIL Handbook 217B are used in these calculations for several reasons. One, the real life failure rates are probably higher than the levels shown in the handbook. The number of units will be too small to obtain real reliability data and a more conservative analysis approach is desirable. Also, a conservative estimate was desired in the design as once the architecture was established, further redundancy is eliminated. The results, however, are not very sensitive to the individual element reliability as the significant change in reliability results from redundancy.

The resulting system architecture selected is shown in Figure 4. The only single point elements are the star scanner optics, the reaction control system supply, the solid rocket motors (SRMs), and the structure. The redundant IMU consists of three groups of instruments. Two of the three groups contain two gyros, two accelerometers and associated electronics. The third group contains one gyro and one accelerometer and associated electronics. The internal physical arrangement and functional redundancy is such that any three of five gyros and any three of five accelerometers are adequate.

Avionics consists of two parallel strings configured so that either string can perform all computer and control functions. Full cross strapping at different points in these strings was not found to be cost effective. A redundant telemetry and communication system was not cost effective because of a redundant self-actuation circuit. Redundant thrusters are provided at each of six locations. Each thruster has two redundant solenoid valves. Redundant separation nuts are provided at eight locations such that either of the two nuts will allow separation of the stages. Redundant safe and arm devices with parallel explosive trains to

the igniter are provided on each solid rocket motor.

Conservative de-rating of each electronic part is the most cost effective way to achieve higher reliability in the design. Both electronic and thermal stress de-rating are necessary. Figure 5 shows four typical examples of de-rating used in the IUS design. Use of the allowed voltage temperature de-rating for capacitors, as an example, will result in 77% reduction of the part failure rate. Individual part de-rating is accomplished during the design process. The electrical stress is calculated and parts are selected to be within the allowed de-rating. The part operating temperature is estimated by thermal analysis of the package. Where necessary, the thermal environment is reduced to the allowable range by providing heat conduction paths. Where de-rating can't be accomplished in a reasonable manner, a cost trade is required. The cost of an alternate design versus the impact on reliability of the higher temperature or electrical environment can be evaluated using the cost model. The actual part thermal and electrical environment are then verified during development and qualification tests.

A good failure mode and effects analysis (FMEA) process involves direct participation by the designer. This is essential as no one understands the design circuitry and functions better than the designer. System reliability personnel should provide additional input and support, including overall FMEA structure, critiquing the designers analysis to make sure it is failure oriented rather than success oriented, and determining system level failure modes and probabilities.

To the greatest extent practical, single point failures identified by the FMEAs should be eliminated from the design by providing redundant paths. Single points are allowed in the IUS design only if: (1) redundancy to eliminate the single point is not possible or practical such as the solid rocket motors; or (2) the probability of a single point failure is low and redundancy to eliminate it is not cost effective, such as staging connectors.

The justified single points are evaluated against the following registration criteria: Does the part have operating or shelf life limitations? Is it difficult to manufacture or procure? Does it have a known poor history? Is there a lack of reliability history? Has a processing deficiency either been experienced or anticipated?

If the item meets one or more of the criteria, it is entered on the registered item list. A registered item control plan is prepared and implemented for the item.

This plan would include, as necessary, additional in-process inspections, additional mterials and process controls, additional testing (both destructive and non-destructive), special part handling, tracability of each part and where all others of the type and lot are located and use of further conservative de-rating. This approach should control the parts and further reduce the failure probability.

Another action during the design phase is to plan the production reliability verification testing. The burn-in test hours and environment conditions such as vibration and thermal cycling must be sufficient to cause the infant mortality defects to be hard failures. An adequate burn-in test program can be an effective approach to reducing the system failure role.

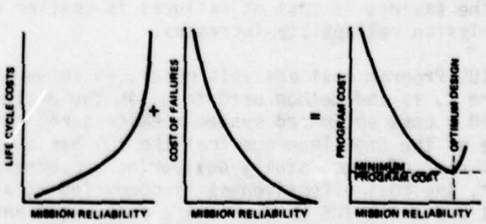
The effectiveness of the 50 hour burn-in test for SRAM avionics hardware sets is shown in Figure 6. Fewer than one in 100 units failed during the last hour of testing versus over one in ten units during the first hour of the test. Both thermal cycling and vibration were imposed on the equipment during the burn-in testing.

Another technique which can significantly improve the mission success is the use of sneak circuit analysis of hardware and software and modifying the design as necessary. Sneak analyais uncovers latent or sneak circuit conditions that would inhibit desirect functions or cause undesired functions to occur without a component having failed. The analysis provides an independent check of the design in that it identifies single failure points, unnecessary logic or components or improper application of redundant paths. The method involves a computer-aided development of the design circuitry into simplifed network trees which can be analyzed to identify sneak paths, or sneak timing. Several spacecrafts have had sneak circuit analysis conducted on specific subsystems. On the global positioning system, the subsystems evaluated included the electrical power, control circuits, interfaces with the digital logic and logic analysis of the dual command decoder.

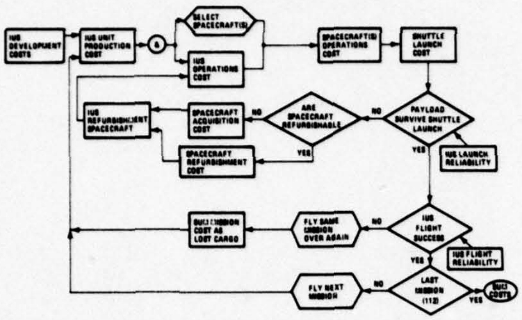
The analysis identified a sneak path that would cause the spacecraft to tumble. Redundant thrusters would fire when firing a primary thruster in a different axis. On the application technology satellite a condition was identified in the automatic deployment sequence that could cause simultaneous firing of two or more squibe which could have resulted in loss of the spacecraft.

In conclusion, the design phase is the time to build in the mission reliability and there are techniques available which, if consistently and effectively used, can significantly improve mission success.

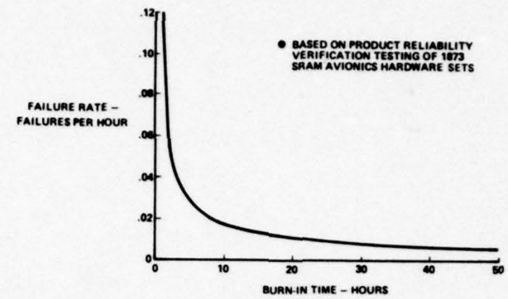
System Architecture Optimization



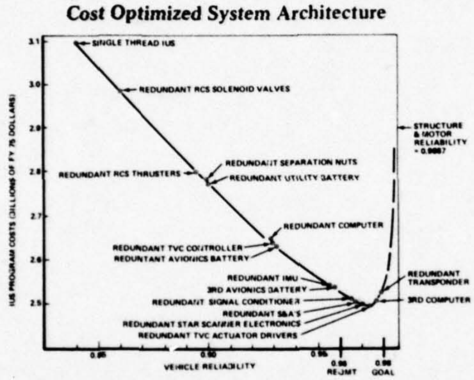
IUS Program Cost Model



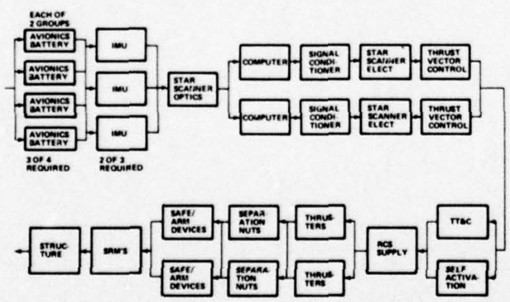
SRAM Burn-In-History



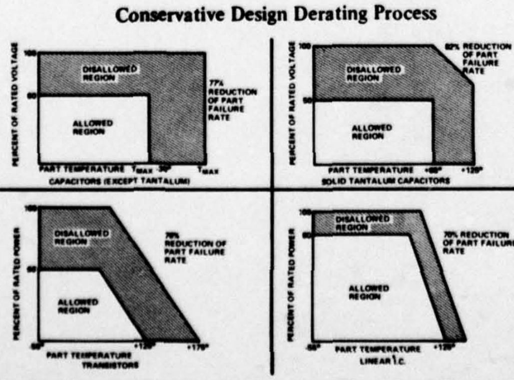
Cost Optimized System Architecture



IUS System Architecture



Conservative Design Derating Process



Richard Schwartz

Vice President and Division Director
of Satellite Systems
Rockwell International

Designing For Mission Assurance
at Subcontractor

- Management
- Contract Type
- Schedule
- PDR Period
- CDR Period
  - Prototype Hardware
- Hardware Fabrication
- Test
- Shuttle

Management

- Establish single point for contract management at prime
  - Engineering vs. contracts
- Brief total subcontract team on where his piece fits in the total program
- Visits
  - Often by key members of management
- Technical assistance
  - Some areas must be provided by prime
  - (EX) Radiation
  - (EX) Dynamics
- Information from other program issues
  - Government SPO to SPO

Contract Type

- Fixed price
  - Best for cost control
  - Technical scope
  - Cost vs technical drivers
  - Poor choice for development contract
- Cost
  - Need tight realtime controls
  - Contract supportive of technical excellence
- Awards/Incentives

Schedule

- Tight but realistic schedule
  - Design time
  - Parts procurement
  - Breadboards
  - Engineering model
  - Fabrication
  - Test
- Definable milestones

Preliminary Design Review Period

- Requirements
  - Integrate schematics into total system
  - Does design do what was intended
  - Performance changes
- Fabrication
  - Process Controls
  - Parts
  - Facilities
- Test
  - Layout Test Plan
  - Sufficient Test Points
  - Support Equipment Design

Critical Design Review Period

- Performance Requirements
- Redundancy (SPF)
- Specialists
- Nonperformance Design Items
  - Mechanical/Vibration
  - Derating
  - Timing
  - Thermal
  - Material
  - PC Board Layout (Inspectability)
- Test
  - All Mission Sequences Tested
  - All Redundancy Tested
  - 1540 and 1541 Requirements Properly handled
  - Instrumentation (Testability)
  - Protype Hardware

Prototype/Engineering Model Hardware

- Build To Production Drawings
  - Commercial Parts
  - Production Fabrication Personnel
- Test
  - Performance
  - Environmental
    - Temperature
    - Vacuum
    - Vibration
  - Instrumentation
    - Thermocouples on Critical Boards
    - Accelerometers on Critical Boards
    - High Response Current Measurements

Richard Schwartz
Vice President and Division Director
of Satellite Systems
Rockwell International

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        - Vibration
    - Instrumentation
        - Thermocouples on Critical Boards
        - Accelerometers on Critical Boards
        - High Response Current Measurements

Fabrication

- Process Controls (Documented and Agreed To)
  - Solder
  - Conformal Coat
  - Component Mounting
- Module Level Test
  - Functional at end of fabrication at high and low temperature
- Fabrication Audit
  - By process disciplined engineers
  - Paper System
  - Review first production hardware
- Discrepancy Reporting
  - Make all failures reportable
- Inspection

Test

- MIL-STD-1540A
- Failure Reporting/Analysis
  - Report and Analyze ALL
  - Resolve Prior to Acceptance
- Data Review
  - Detail Review at All Levels
    - Module
    - Box
    - Environmental
  - Establish Buy-Off Team for Each Box

Box Level Acceptance Test Flow (Per 1540)

☐ Functional

☐ Random Vibration

☐ Functional

☐ Thermal Cycling $\approx$ 17 cycles

☐ Functional

Thermal Vacuum Cycling ☐ 1 Cycle

Functional ☐

Final Inspections ☐

Ship Δ

Shuttle

- Weight
- Volume
- In-Orbit Test

Items For Added Emphasis

- Workmanship Standards
- Better/Faster Flow of Other Program Issues

TEST CONSIDERATIONS

Joseph Statsinger
Vice President and General Manager
The Aerospace Corporation

Test Program Objectives

- Evaluate Design Alternatives as Design Evolves
- Demonstrate
  - Design Adequacy
    - Functional
    - Environmental
  - Compatibility of System Elements
  - Overall System Performance to Meet Specifications
- Provide assurance of proper manufacture, processing and workmanship
- *Predict the future*

Elements of Test Program

- Test Planning
  - Developmental
    - Stress
    - Margin
    - Life
    - Functional
  - Qualification
  - Acceptance
- Design of product for testability
- Design and control of test equipment
- Design of system for test data processing and evaluation
- Provision of hardware and software resources for failure analysis and diagnostics
- Documentation
- Personnel training and motivation

Product Design for Testability

- Availability and accessibility of test points
- Accessibility and stability of control settings
- Deisng for realistic testing
- Separability of redundant elements for testing
- Accessibility of sub-assemblies for removal and replacement
- Availability of telemetry points

Design of Test Equipment

- Provide for required accuracy and resolution
- Provide capability for positive and negative testing
- Design for fault protection
- Provide interlocks
- Consider human engineering aspects
- Assure adequate design controls
  - Specifications
  - Standards
  - Configuration Management

Predicting the Future

- Short Term - Expendable Boosters
  - Stress Testing
  - Test Realism
  - Timing of Tests
- Long Term - Spacecraft
  - Real Time Life Testing
  - Accelerated or Simulated Life Testing
  - Stress Testing
  - Modeling and Phenomenology
  - Test Realism

Software Categories

- Mission Critical - Time Urgent
  - Software anomalies produce catastrophic failure
- Mission Critical - Not Time Urgent
  - Recovery Procedures Available
- Off Line - Not Mission Critical

Software Testing Considerations

- Mission Critical - Time Urgent
  - Provide automated redundant/back-up capability if possible
  - Test all modes and mode combinations
  - Provide for independent test and validation
- Not Time Urgent
  - Test all modes and mode combinations if possible
  - Validate safing procedures
  - Validate recovery procedures
  - Provide capability for and validate on-board re-programming for spaceborne software

Summary

- Some areas needing further study
  - Development Testing
  - Product Design for Testability
  - Availability of Test Beds
  - Design and Control of Test Equipment
  - Testing for Long Term Performance Prediction
  - Software Testing and Validation
  - Personnel Training and Motivation

CONCLUSIONS

Paul E. Wright
Vice President, Engineering
RCA Corp.

Now that you have heard from five of the members of the Panel, let me conclude with a few observations. There is a popular myth that most of the failures on spacecraft are mechanical, that derives probably from the spectacular nature of a failure in the launch process. Statistics that I have studied indicate that spacecraft problems serious enough to affect mission objectives divide about equally between mechanical and electrical failures. The general approach to be taken in reducing mechanical failures is substantially different than that for protection against electrical failures. Careful attention to concept, extensive modeling, and careful subassembly and testing, are approaches to mechanical problems. Most electrical failures can be dealt with, however, through process standardization and part qualification.

It is clear to everyone in this audience, I am sure, that the Shuttle era will change the boundary conditions against which we design spacecraft. We will see substantial reductions in the number of launch failures because of a well tested, well designed, Shuttle launch system. We will, however, have to deal with the new questions of reliability that come from deploying the Shuttle cargo. A new set of operations, involving mechanical and stabilization procedures, will provide their own set of reliability considerations. Designers must also keep in mind the new opportunities provided by Shuttle to do new things, like the repair of a spacecraft, the adjustment of its orbit, and even the retrieval of a temporarily defective spacecraft for subsequent repair and redeployment. Shuttle offers an entirely new set of cost tradeoffs. Now, the system is essentially volume sensitive rather than weight and power sensitive as has been our past experience. I could go on for an hour but let me terminate the comments on the Shuttle era by pointing out that we will see a multiple interface situation with Shuttle; the government will be paying many industrial firms to build satellites, all of which will come together in the bay of a single Shuttle spacecraft for transport to suborbit. This is a systems integration problem, as challenging as those faced in the Apollo Program.

My final concluding remarks will deal with some future trends. First, the role of "non industry" organizations like JPL, Lincoln Laboratory, and Aerospace in the design process will be an expanding one. Secondly, the Space Shuttle offers an opportunity for future spacecraft design which will have far reaching impact; that is, assembly of structures in space. This will change our design philosophy in areas such as subassembly size, level of test, repair and replacement. A third consideration for future design trends is appropriate use of the data base. In spite of the fact that we have all been in this business for well over a dozen years, it is still a very young industry. We are just now beginning to build the data base so that statistically significant conclusions can be drawn and used for the basis for generalized design rules. Finally, I believe that the aerospace industry, (both the government and industrial parts) must reassess its conservative attitudes, particularly with regard to advances in electronics. We can not afford to become extensive risk takers in the decades of the 80's and 90's but we should re-examine the leader/follower roles. Our practice has been to use technology in spacecraft only after it has been thoroughly exercised by other non-space users. The result has been a substantial lag by the aerospace industry in the use of solid state products. I suggest that Mission Assurance may very well be reduced rather than enhanced by that attitude. I think the future demands that we consider optimizing our life cycle costs by accelerating the maturity process of LSI and VLSI, so that we can experience the significant mission assurance advantages that are inherent in these technology concepts. The use of distributed microprocessors, solid state memories, solid state replacements for traveling wave tube amplifiers, etc., will be the basis, I believe, for improvements in Mission Assurance through design for the decade ahead.

WORKSHOP A
DESIGNING FOR MISSION ASSURANCE

Co-Chairmen

Mr. Edward T. Bobak
Systems Engineering Director,
FLTSATCOM Program
The Aerospace Corporation

Mr. Emery I. Reeves,
Engineering Operations Mgr., SSD
TRW

AGENDA

Wednesday, April 26

0830-0845	Introduction	Mr. Edward T. Bobak, Aerospace
0845-0915	Overview	Mr. Emery I. Reeves, TRW
0915-0945	"Program and System Design Approaches"	Mr. Anthony J. Iorillo, Hughes Aircraft
0945-1015	"Product Design and FMEA"	Mr. Phillip D. Crill, Ford Aerospace & Comm. Corp.
1015-1030	Break	
1030-1100	"Design for Test"	Mr. Anthony J. Aukstikalnis, RCA Astro-Electronics
1100-1130	"Designers' Role in Manufacturing, Test & Operations"	Mr. Robert C. Koche, Lockheed LMSC
1130-	"Prevention of Design Faults: Redundancy"	Mr. Kenneth P. Timmons, Martin Marietta
Lunch		
1330-1500	Subgroup Discussions Aimed at Defining Design Issues which Affect Mission Assurance	(All workshop members)
1500-1515	Break	
1515-1700	Subgroup Discussions Aimed at Identifying Recommendations	(All workshop members)
1700	Adjourn	

DESIGN FOR MISSION ASSURANCE WORKSHOP
~~OVERVIEW~~

Mr. Edward T. Bobak
Systems Engineering Director
The Aerospace Corporation

Imperfections in design are the most predominant causes of catastrophic mission failures. In order to alter the trend and improve the probability of mission success, it is necessary to review the design process in its elemental forms. By so doing, weaknesses can be identified and constructive steps initiated to improve the process.

The format of the Design Workshop was designed to focus the attention of participants on significant elements of the design process. First, by responding to a detailed questionnaire that requested opinions on the importance of design elements. Secondly, by utilizing presentations on selected topics by industry experts. Finally, by group discussion of agreed-upon critical issues that lead to constructive recommendations for change.

THOUGHTS ON IMPROVING THE DESIGN AND VALIDATION PROCESSES

Anthony J. Iorillo
Associate Manager, Technology Division
Space and Communications Group
Hughes Aircraft Company

As this conference attests, Mission Assurance is a broad topic involving many disciplines and points of view. Since each of us tends to be a product of specific experience, the class of failures or errors to which we are most sensitive varies. Hopefully, the frank sharing of our problems and thoughts on avoiding repetition of our errors, when summed, will serve to inspire creative dialogue and motivate the upgrading of techniques to the benefit of all. Consistent with this spirit, I will discuss facets of our experience with misfortune at Hughes and share with you some ideas on how we might improve our performance. Specifically, I wish to focus on the management of the design and validation process for satellite systems.

Encompassing one hundred and fifty satellite years, our flight logs record a wide spectrum of equipment failures and degradations. Among these are found the typical random electronic component failures and the premature degradation of batteries, receiver gains, traveling wave tubes, mechanism friction and the like. Another significant class of entries involves flaws in workmanship or marginal unit designs which escape our screening test filters. Generally, these failures have been accommodated by redundancy, initial margin or operational flexibility inherent in the satellite design. Missions have degraded below expectation but have been performed nonetheless.

The failures which had immediate catastrophic consequences involved no flaw in workmanship, random part failure or component degradation. I refer to the launch of vehicles whose characteristics were not well understood, for which test and analyses were inadequate. Specific examples are:

1. Explosion of Intelsat II apogee kick motors because we did not properly analyze the thermal conditions at ignition;

2. Instability of NASA Application Test Satellite due to late addition of a liquid heat pipe whose effect on nutation was incorrectly assessed; and

3. Loss of a portion of a payload on a USAF satellite because a single fuse, in series with redundant receivers, blew during a switching sequence.

In addition to outright failure, we have had our share of close calls whose consequences were serendipitously tolerable.

1. USAF TACSAT nutation resulted from an oversight in the specification of its mechanical despin assembly damping characteristics.

2. Much larger than anticipated, dynamic unbalance of a meteorological satellite resulted from incomplete analysis of vehicle dynamics.

3. Hang up of a number of pointing mechanisms and rubbing between a despun/spun interface because we did not properly account for thermal environment.

4. Unexpected mode change in attitude control system on a USAF satellite because of the design shared clock signals with a telemetry unit which was by intent automatically turned off in eclipse.

This partial list of examples serves to fix ideas on the type of errors I refer to. Hindsight makes them seem the result of ineptness. Yet they were made by motivated and competent people whose successful accomplishments provide testimony to their skills. I have reviewed recently a summary of failures and anomalies compiled by SAMSO. I find that design oversight occurs often enough in this larger data base to suggest that it is a general problem. I also find that our industry has reacted to this body of experience. Recognizing the large increase in complexity of military satellite designs in the last decade, normalized performance has in fact improved. The prospect, however, is that the next generation of systems will be even more complex and a fresh generation of engineers will be involved. Unless we are concerned with the passing forward of information and improved methods, we can be assured that old errors will be repeated along with the predictable new set.

I have attempted to analyze the underlying reasons for the failures cited above with the hope of extracting some generalizations. Notwithstanding the classic danger involved in this attempt, I submit the following views:

1. A shortcoming in our management system is the extent to which we review systematically the implicit assumptions underlying analytical models used to predict and validate performance and establish qualification test conditions and criteria. We assume, too often, that the specialists involved set the problem up accurately and we start the review process by accepting and assessing results. Few program managers, system and mission engineers or hardware designers are ever involved in a systematic review of an exposition of the analytical model and its degree of fidelity to actual hardware or the intended environment and application. This is contrasted with the relatively disciplined manner in which we require hardware designs to undergo rigorous validation tests. Yet as we experience, omissions in modelling and simulations—dynamics and control, thermal and in some fewer cases structural modelling—are the basic causes of our most dramatic failures.

2. As a body, program and technical management rarely know in detail what elements and possible modes of the design are not tested functionally or environmentally. Consequently we test some modes accidentally for the first time late in system test or, worse, in orbit and are surprised by the results. (In a specific case, failure detection and toggle circuitry which was relied on to assure

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automatic switchover to a redundant control unit in the event of failure was never burned in during system test. Failure is not a standard sequence. The contract required a 500 hour burn-in of all units in system test. However, much of the circuitry in many units is effectively dormant even with power on.) More generally, many modes of a complex interactive system which do not contribute to primary mission performance parameters or occur in normal operations are frequently overlooked in synthesizing the system test program. There is basis to the lore that we learn more about the design by investigating the results of command sequence errors in system test than we learn when exercising correct normal sequences.

3. The discipline of performing and reviewing FMEAs is not yet a well established part of our system engineering process. It is tedious, difficult and requires experience to perform a comprehensive analysis. We are only now beginning to recognize this and must plan our resources in advance at a level commensurate with the task.

Contractor Review

We are attempting to establish improved review procedures to surface, in a systematic manner, underlying assumptions in analytic models used to establish the adequacy of design. In particular we plan to review dynamic and control models, thermal analysis models and structural dynamics and stress models. In the presence of a general senior audience comprising engineers familiar with mission sequences and hardware operations, as well as technical specialists, we plan to require analysts to explain the implicit assumptions in their modelling, the simplifications made to render the analysis tractable and the depth of the data base from which they extract physical parameters. What we attempt to achieve is a common understanding of the fidelity of the modelling to the detailed design, the actual environment, and the intended use of the satellite. In many cases, we find this type review inspires relatively simple measures to develop experimental data where the models fall short. We also hope to uncover systematically those facets of the analysis for which no validation test is planned. The intent of course is to surface risks and uncertainties to programmatic levels which can take correction or alternate action.

The key to these views is the recognition of the leverage the analytical functions have on mission success and the planning of resources in advance to see that the analyses are carried out thoroughly during development. Last minute independent review teams assembled prior to launch attempting to review years of technical activity cannot be relied on to provide a comprehensive, in-depth judgment. In general, the problem data they evaluate are assembled for them by program staff and they rarely generate new concerns. A staff of competent engineers assembled at CDR, for example, who are chartered to accomplish independent validation analyses comparing notes with the contractor on a scheduled basis is a more reliable investment of independent effort. The activity of this staff may be viewed as an early phase of the independent readiness review task.

For this approach to be effective several conditions should be avoided:

1. The collusion of contractor and Aerospace analysis teams in the difficult to resist improvement of the design process beyond the acceptable point of adequacy.

2. The unwillingness of the validation team to accept sensible risks because validation is by its very nature a no win task.

3. The creation of a bureaucratic entity which outlives its usefulness – the teams should be dismantled after the system design is verified by first article performance in orbit.

It is my belief that proper attitude in the USAF, Aerospace and contractor management organizations can preclude these potential hazards.

The Future

I have not mentioned the root cause of the design and qualification problems I discussed earlier because it is obvious. Unlike our colleagues in airborne and ground based aerospace development, we have not had the luxury of flight test or in situ test for final verification. Lacking zero-g and sufficiently large STV test chambers, we rely more on analytical verification than most technical development fields. The reason is simply that launch costs are so high that we have not been able to afford the routine test of prototypical vehicles in orbit. Consequently, we have had qualification test vehicles sitting in hangars while we completed the design process with the first flight articles.

The advent of the Space Transportation System should cause a dramatic change in this way of doing business. With proper management of the STS resource, a large decrease in cost should be forthcoming such that launch of a satellite will be a small fraction of satellite cost. The implementation of a test flight in the prototype development program should become as routine as a final test flight for new aircraft.

I look forward to this prospect because it would allow us to do a much better job of finishing development before we commit large investments in flight articles to operation.

I hope those thoughts were of general interest and that you find some of the ideas useful.

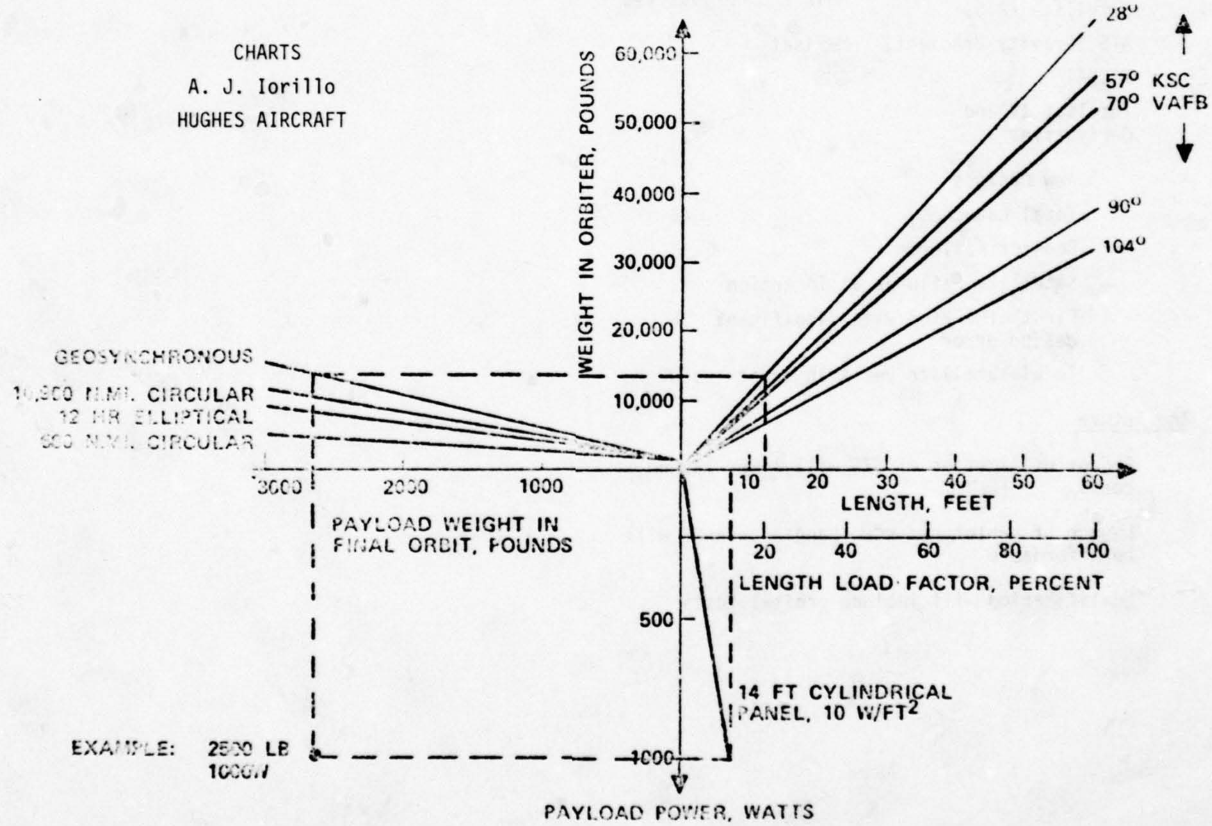
Similarly we are striving to establish a more formal dialogue between mission operations specialists, system engineers, hardware designers and system test engineers. The normal channel of information flow through specifications is just not sufficient in complicated system developments to assure the hardware designer understands sufficiently well the details of the external or the interactive environment, within which his equipment must function. We hope to surface possible incompatibilities, interactions and modes which are not intended. Further we will ask formally which part of the hardware is not exercised environmentally or functionally in the test program at unit and subsystem levels. This latter activity will be implemented in concert with formal performance verification analyses which, though tailored to

contract end item requirements, comprise the basic driving force for structuring the functional and environmental test program.

Independent Review

Early in the SDS program, as a result of experience with the dynamic instability encountered in the DSCS II program, an independent Aerospace stability and control validation team was established. This Aerospace team, comprising a competent staff of analysts, worked in parallel with Hughes to model in detail and analyze the ambitious SDS control system. As a result of the in-depth work of this team, the technical reviews of our progress in this area were thorough and constructive. Flaws in our design were uncovered by this Aerospace team and a cooperative effort was undertaken to correct the deficiencies. As the Hughes systems manager, I was always grateful for having this resource available to help whenever problems arose. Similar, though not always as comprehensive, or as cooperative, independent validation analyses were performed during the program in areas which seemed to us critical. The independence of the Aerospace team and the often different perspective it brought to bear on the task were important factors. I propose that this independent validation be extended in a uniform manner to all areas of the validation process which cannot be verified by test. The cost to the government would be a relatively small percentage of the developmental cost for any system. Moreover, the effectiveness of Aerospace's monitoring function would be greatly improved because they will become much more familiar with all important details than is possible through reviewing contractor work. An extension of this concept to the task of developing a model for all possible satellite modes in the manner I described earlier makes sense. An independent construction of the mode matrix would result in a better review of the design and the contractor's qualification test program.

CHARTS
A. J. Iorillo
HUGHES AIRCRAFT



Recurring Design Errors

Omissions in simulation and analysis of thermal environment

Omissions in simulation and analysis of vehicle dynamics

Unanticipated interaction of vehicle modes

Single point failures not screened

Observations of Technical Management Shortcomings

Review and validation of analytical models not sufficiently comprehensive; risks and uncertainties not surfaced to program management systematically

System qualification test programs focus on primary performance parameters and normal operations; interaction of nonstandard modes not systematically analyzed or stimulated

FMEA discipline and review not yet established part of system engineering function

Suggestions For Improvement of Review Procedures

Implicit assumptions, simplifications, and depth of data bases involved in performance verification analyses should be reviewed systematically by senior audience of system engineers, mission operations engineers, test engineers and program management as well as technical specialists

Standard and nonstandard satellite modes should be systematically identified; modes not tested should be surfaced to management

Independent validation should be strengthened

Hughes Satellite Programs

Syncom	HS 318
Intelsat II	Satellite Data System
Applications Technology Satellite (ATS)	Anik and Derivatives
ATS (Gravity Gradient)	Marisat
TACSAT	GMS
Intelsat IV and Derivatives	

New Designs	11
Total Launches	45
Booster Failures	5
Satellite Failures at Insertion	3
First of a kind with significant design error	6
Total satellite years in orbit	150

The Future

Proper utilization of STS will lower launch costs

Launch of prototypes now "hangar queens" will be affordable

Qualification will include orbital tests

PRODUCT DESIGN AND FMEA

by Phillip D. Crill
Staff Engineer to The Manager of Programs
Ford Aerospace & Comm. Corp.

Ed Bobak has asked me to talk about the use of FMEA in connection with design for Mission Assurance. These words immediately turn me off. How can I assure a mission? The "mission" for a military communication satellite is to allow some general who is completely surrounded by Russian tanks in the middle of Bavaria to get on his portable radio and obtain permission from the President to drop a couple of "nukes" on the tank's headquarters. I can't assure that the general will get through, my company can't assure that, and I doubt even SAMSO can assure that. What I can assure is that when the satellite gets into orbit, it will operate as predicted.

Operational people are almost as smart as equipment designers and suppliers. They come up with amazing methods when necessary to utilize malfunctioning equipment to accomplish their missions. Notwithstanding their ingenuity and mission success, we as equipment suppliers have failed in our mission when such extra steps are required. Therefore, I will direct my remarks to one facet of the job we undertake to accomplish, assurance that the equipment will work as predicted.

We can dream dreams of glorious equipment, we can plan, analyze, or set up elaborate operational schemes, but when the equipment goes into operation it must work reliably. To achieve that, only two things really count; first, what was put on the manufacturing drawing, and second, how faithfully the manufacturer followed the drawing. It is an old cliche, but nonetheless true, that we can only build in quality and reliability. We can test to determine deficiencies and inspect to determine errors but in the end operational reliability must be built in. Anything we can do to assure that the manufacturing drawings represent what we intend, and are the best that can be accomplished, is a large step toward assuring mission success. FMEA can play a large part in this vital step.

The purpose of FMEA is, then, to assist – and let me underline the word assist – the designer to turn out correct drawings by performing a systematic review of the design with experts from all disciplines. I underline the word assist because FMEA can easily become a contest between two equally good, but different, ways of doing things. Also, FMEA can easily become an entity unto itself. It can become an empire primarily motivated toward survival, more concerned with methodology, form, and public posture than changes on a drawing. It does no good for someone to show you a well documented, beautifully written and published report and then say "We told you so" after a failure occurs in orbit. What was put on the drawing is all that matters. Only the designer changes drawings, so FMEA's purpose is to assist the designer.

A secondary output, of course, is the check and double check which assures the design is sound and potentially successful.

To prevent a continuous difference of opinion between designer and the FMEA reviewer, a well defined and established level of design requirements and design margins must be maintained. This must be adhered to by in-house designers, managers and FMEA reviewers, as well as by the customer, or complete chaos reigns and the program managers soon assume a referees' role.

We at Ford are proud of what we consider to be a very low on-orbit failure rate. Part of this success has to be shared with the use of FMEA and the removal of potential failures before they have a chance to occur. We have split FMEA into two parts and employ knowledgeable people in both parts. FMEA is split between electrical circuit FMEA and product design FMEA.

Over the years we have tried various methods for circuit FMEA. Fault tree analysis was used for a time. In this method, a logic diagram was constructed of 'what if's', i.e., what if this transistor shorts; and then we worked upward to conclude the transmitter had no output. This method had a lot of appeal. It was visible and could be used at all levels, but it was cumbersome and wasn't always systematic. We also tried the tabular narrative method. This method permitted more detail and was easier to follow for the first few steps, but it was difficult to follow the effects of a part failure all the way to the satellite level. We have now adopted the MATRIX METHOD.

In the MATRIX METHOD, a series of cross-hatched matrices are formed where the vertical lines represent constituent components, and horizontal lines represent effects. The intersection is coded with possible failure modes. Thus, for this simple logic circuit, piece parts – resistors R-1 through R-4 and the transistor Q1 and amplifier U-4 – are represented as vertical lines. Likewise, the DC input and return lines, the signal input lines and the signal output lines are represented vertically. Each of these components is allowed to fail in all reasonably possible ways. Transistors, for instance, fail short and open. Resistors, on the other hand, would reasonably only fail open.

The effect of these failures are then identified on the HORIZONTAL lines. Thus, in our example, opening or shorting of transistor Q1 has the effect of no output on both A and B, while the opening or shorting of U-1 affects only output A. No effect or out-of-spec effect is two lines. We always include the matrix although in this particular example only "no failures" result. A similar matrix is made up for each small circuit element in the system.

At the next level, horizontal lines from Level 1 become the vertical lines of Level two, and added to them are other circuit matrices. Using the effects from Level 1, the effects at Level two are identified on the horizontal lines. The horizontal lines from this level become the vertical for the next level, on up to the final system level.

An example of the tiered effect and of how a failure mode can easily be overlooked is the value driver circuit for the hydrazine thruster on the NATO III spacecraft. The valve drivers are contained in their own box located on the equipment platform. They are connected to the thruster valves by cable harness. The thrusters are located on the periphery of the spacecraft. They are 100% redundant and isolated from each other. Each thruster has its own

valve driver which is isolated from all the others. Not only that, but within each valve driver is parts redundancy. Power to operate the thruster valve comes from a protected plus bus through the valve coil to two transistors in series. If one transistor fails short, the other transistor will open the circuit and close the valve. This represents super redundancy and we are theoretically protected all around. But that is not what the FMEA said. FMEA said one of the failure modes is a short to structure of the harness wires. The power return at one point is connected to the structure. Should a short occur between thruster and driver, the valve would be held permanently open and the satellite would be moved considerably out of position and soon out of hydrazine. The solution was fairly simple. We moved the valve drive to the other side of the valve coil. That is, put it between the plus source and the valve. Now should a harness short occur, no current flows unless the valve driver is turned on. If the short is hard enough, the thruster may not respond when the valve driver is activated and, indeed, the power line fuse may blow. But the spacecraft is intact and the redundant thruster can be used. This particular circuit also had a very serious and common product failure mode which I will discuss in a minute. The amplifier consists of two redundant amplifier chains of three series transistors each. The first two amplifiers are one-half of a dual transistor package. One of the failure modes is for one of the transistors to short. Unfortunately, when one transistor shorts, it overheats the second transistor and, in about 90% of the cases, will cause it to short also. Both transistors shorted will cause the thruster valve to remain open with disastrous results. Looking at this circuit now, it appears obvious that the design is unacceptable and that any designer worth his salt would not use it. However, if it is so obvious, why do we have eight spacecraft in orbit right now using this circuit, and why did we launch two of them after the potential problem was uncovered on NATO III? FMEA is a waste of money unless we believe the results and do something with them.

We at Ford believe the matrix system has considerable merit over other systems and we are involved in an effort to computerize it to speed up the process.

Product FMEA is not as far advanced as circuit FMEA but has been used at Ford on the NATO III program and on all our commercial programs since NATO III.

In the valve driver circuit I pointed out an example of a single transistor package containing two transistors that represents a potential loss of redundancy. Another very common area is the printed circuit mother board in a box that contains the redundant circuits. A failure in one-half the circuits can easily propagate to the other half. To circumvent this, we at Ford make a practice of putting redundant circuits in completely separate boxes.

Tolerances and tolerance buildup can appear in some very unexpected ways. We are familiar with clearances on moving parts such as the despin motors or the solar array drives, and sloppy mounting holes, where the washer half falls through. Once we had a series of circuit failures attributed to ceramic chip capacitors. Investigation showed that some of the capacitors had small bumps on them that stuck out past the nominal limit. There was not enough room to fit them in, so one of the technicians was grinding off the bumps. The technician should not have done this, and caught hell for it, but the real culprit was the designer who did not look at the tolerances adequately.

Thermal is another especially nagging problem. The spacecraft thermal personnel are charged with maintaining the baseplate of the boxes within a certain temperature limit. This aspect gets a lot of attention and is usually handled well, but down in a module there is a transistor that dissipates a quarter of a watt. That is a very small amount of power and the transistor is operating well within its rating. But what about the component that is jammed in tight against the transistor and encapsulated in foam? Unfortunately, the designer is engrossed by how he is going to jam all those parts into the small space the spacecraft designer allocates, and thus doesn't get to the subtleties of the thermal aspects.

The specifications given to the designer have pages and pages of requirements about space environment. They cover all the shake, rattle, and roll, plus radiation, vacuum, sun loading, particle bombardment, and now even include space charging. All of this is followed by a simple little paragraph that says "the unit shall be designed to withstand the factory-to-launch environment." The designer of the unit doesn't have time to know, and usually doesn't care, what happens to his box once it gets out of his shop. It is important, therefore, that someone who does know, and who does care, reviews the design.

Every circuit, every module, every component of the satellite must be carefully reviewed by someone concerned about thermal, someone concerned about stress, someone concerned about creep and deformation, someone concerned about manufactureability, someone concerned about assembly and handling. Seldom are all these concerns embodied in one or two people. Working meetings are therefore required for each step of the process.

Let me conclude by saying that FMEA can be effective in improving designs and can also be cost effective. On the NATO III Program, FMEA disclosed 118 single-point failure modes. This occurred after the designers had completed the first round design, and in spite of a firmly established ground rule that there would be no single-point failure modes. Of this 118, 43 were correctable and were eliminated, but the others couldn't be eliminated. Some of the single-point failures were obvious; structure, AKM, hydrazine fuel, etc. The majority, however, were associated with the communications subsystem; input and output filters, antennas, the rotary joint, and, worst of all, the switches used to switch the redundant active units into and out of the circuits.

A firm ground rule of "no single point failures" is obviously unrealistic. Some will exist. FMEA can identify all that remain and allow a judgment to be made as to the seriousness and cost effectiveness of eliminating them.

Properly directed FMEA can be effective. As an empire unto itself, it can emasculate your profits.

DESIGN FOR MISSION ASSURANCE WITH FAILURE MODE EFFECTS ANALYSIS (FMEA)

DESIGN FOR MISSION ASSURANCE WITH
FAILURE MODE EFFECTS ANALYSIS (FMEA)

What Mission?

- "Mission", like "system", can mean anything.
- Mission assurance can, of course, relate to various levels of desired performance.
- Our mission as hardware designers and builders is to provide equipment that works, when needed, and in a manner that was predicted.

What Counts In Design?

Only Two Things Really Count:

- What the designer puts on the drawing.
- How faithfully the production person implements the drawing.

All the rest (engineering, test, QA, reliability, management) is to assure that these two happen and happen correctly.

Failure Modes and Effects Analysis (FMEA)

- Purpose is to assist the designer to get the drawings right by doing a systematic review of the design with experts from all disciplines.
- Secondary output is documented assurance to management that a particular design has high probability of success.
- A prerequisite is a well established design and margin criterion.

FMEA Consists of Two Parts

- Circuit design FMEA
- Product design FMEA

Circuit FMEA Methodology

Fault Tree Analysis

- Pictorial method of projecting effects to system level

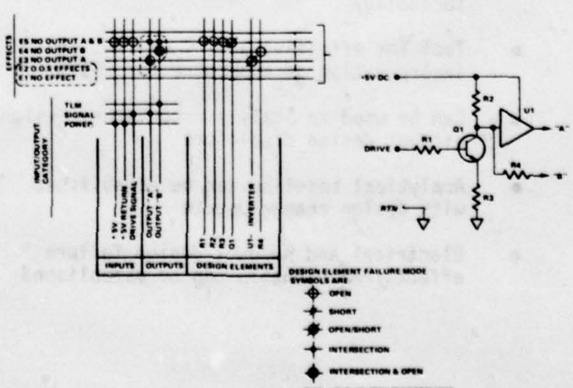
Tabular Narrative Method

- Contains valuable detailed failure mode and local effect information, but is difficult to interpret system impact

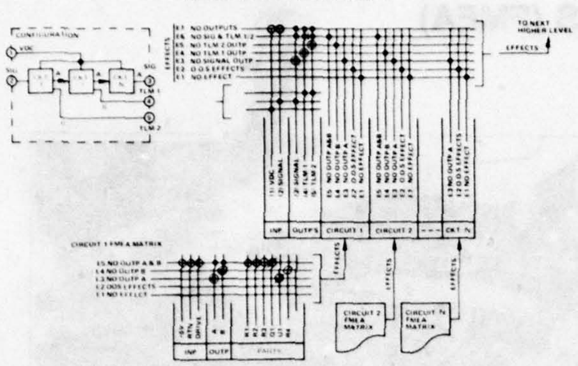
Matrix Method

- Systematic method applicable from lowest level module to complete system

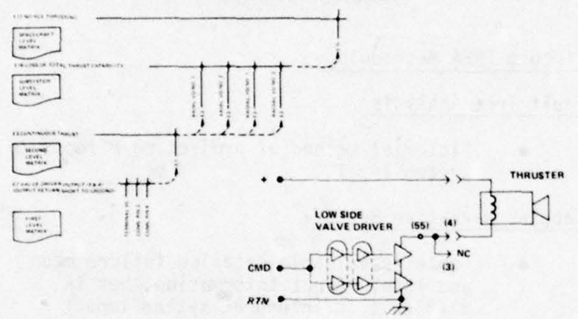
FIRST LEVEL MATRIX



SECOND LEVEL MATRIX



TRACEABILITY EXAMPLE



Advantages of Matrix Method

- Identifies reliability problem areas and single point failure modes
- Systematic accountability of all design elements including solder joints and connector pins
- Relationship and traceability from lowest to highest level
- Can be applied to any type of design technology
- Tool for effective audit, review, and incorporation of subcontractor FMEAs
- Can be used to analyze proprietary design without design disclosure
- Analytical baseline can be established with design change update
- Electrical and product design failure effects/relationship can be established

Product FMEA Methodology

- Not as well structured but just as necessary
- Mechanical equivalent to electrical FMEA
- Requires expertise in mechanical engineering, thermal design, materials properties, and an understanding of electrical-mechanical interfaces

Product FMEA Targets

- Single point failure modes associated with wiring, circuit traces, connector pins, and solder joints
- Single point failure modes caused by single parts having multi-application elements
- Thermal, mechanical, and electrical adequacy in locating, positioning, and fastening parts
- Use of authorized parts, materials, and processes
- Adequate sizing, continuity, and effectiveness of grounding
- Tolerances and tolerance build-up in mechanical parts
- Provisions to prevent degradation of materials prone to cold flow
- Adequacy of hermetic seals and adequacy of venting
- Dissimilar metals and moisture traps
- Adequacy of designs to withstand the environments, on earth as well as in space
- Protection against propagation of failures to redundant assemblies

FMEA Effectiveness

- On the NATO III program, FMEA identified 118 single point failure modes after the designers had done their thing.
- 43 of the single point failure modes were eliminated.

BUILT-IN TEST FEATURES
FOR
ACHIEVING MISSION ASSURANCE

by Anthony J. Aukstikalnis
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Extensive testing is required to insure that an aerospace system will meet or exceed performance and lifetime requirements. This paper explores built-in system, hardware, and software design features which give greater assurance that an aerospace system is completely tested and meets performance requirements. It is intended to stimulate thought leading to more extensive use of built-in test features for aerospace systems.

Figure 1 shows the hierarchy of test for an aerospace system and the major test objectives at each hierarchal level. All testing is oriented toward weeding out design, component, manufacturing, and interface problems at the lowest possible level. In general, eliminating problems at the lowest possible level where they can be more easily detected and solved, is quicker and cheaper than trying to eliminate them during a subsequent level of testing. This paper will concentrate primarily on system test, the highest hierarchal level.

A generalized aerospace system is shown in Figure 2. There are usually four major categories of input/output signals:

- Commands to configure the system for its various modes of operation.
- Input data which is either transduced or used by the system internally.
- Telemetry data used to communicate internal system status. Both hardware and software derived telemetry are included.
- Output data which is either transduced input data or data which is generated within the system itself.

The system under test is characterized by limited internal visibility and, consequently, presents a difficult test and troubleshooting environment. Furthermore, real time constraints place further stringent demands on the test system. To aid the test process, three major categories of test inputs and outputs are usually implemented.

- Test stimuli for on board subsystems which cannot be internally stimulated. Examples are solar array simulators for spacecraft and electrical simulators for sensors which may not be able to be realistically simulated in any other way.

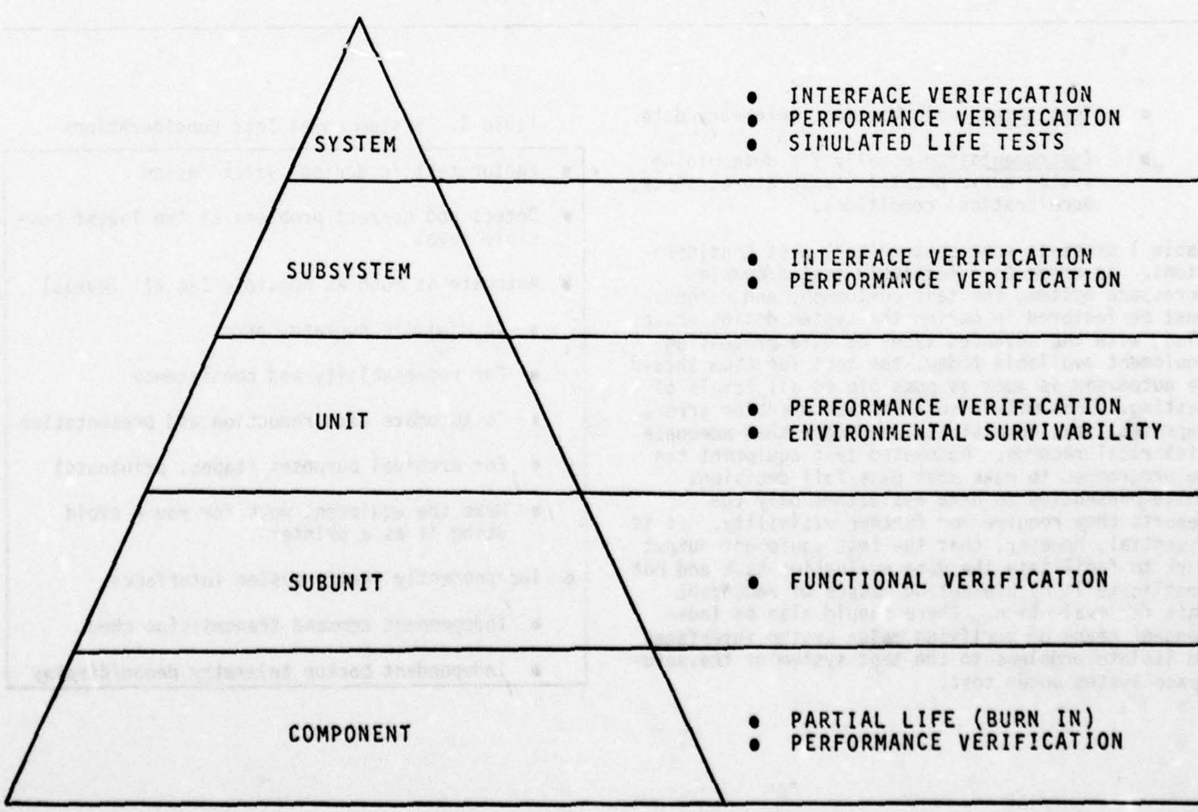


Figure 1. Hierarchy of Test

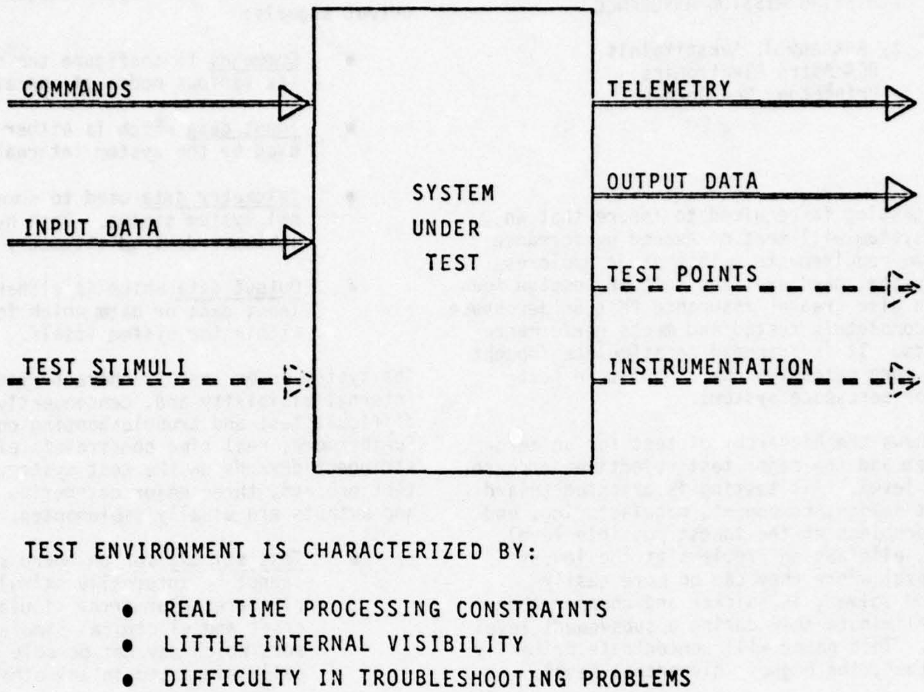


Figure 2. Generalized Aerospace System

- Test points which augment telemetry data.
- Instrumentation usually for determining system environmental (temperature, shock, acceleration) conditions.

Table 1 presents some system level test considerations. In order to effectively test a complex aerospace system, the test philosophy and methods must be factored in during the system design phase. Also, with the advanced types of data processing equipment available today, the test function should be automated as much as possible to all levels of testing. This will result in less operator error, repeatability, consistency, and more than adequate historical records. Automated test equipment can be programmed to make most pass/fail decisions while presenting to data evaluators only the reports they require for further visibility. It is essential, however, that the test equipment output work to facilitate the data evaluation task and not complicate it by presenting masses of redundant data for evaluation. There should also be independent means of verifying major system interfaces to isolate problems to the test system or the aerospace system under test.

Table 1. System Level Test Considerations

- Factor test in during system design
- Detect and correct problems at the lowest possible level
- Automate as much as possible (at all levels)
  - To minimize operator error
  - For repeatability and consistency
  - To automate data reduction and presentation
  - For archival purposes (tapes, printouts)
  - Make the equipment work for you - avoid using it as a printer
- Independently verify system interfaces
  - Independent command transmission check
  - Independent backup telemetry decom/display

Table 2 shows system design features which facilitate testing while giving more visibility, better troubleshooting capability and more comprehensive testing. These system design features can be divided into two major categories:

- Features which decrease system capability, e.g., simplified command and telemetry formats. From a test viewpoint, simplifying these interfaces leads to less and faster processing in what is normally a very constrained real time environment. Also, more comprehensive testing results since there are fewer formats to test and those that are present can be tested more often. On a component count basis, the system is also more reliable since less components are required to implement the simpler command and telemetry subsystems.

- Features which increase visibility and troubleshooting capability, e.g., test points and error codes. Although more processing is required, the additional testing and visibility gives more assurance that the system will meet its performance requirements over the life of the mission.

Here we see a fundamental tradeoff which accompanies the designing in of built-in test features. Built-in test features increase component count and, therefore, slightly decrease reliability estimates based on component failure rates. The assurance gained by additional visibility at the system level far outweighs the lower reliability even though it cannot be expressed mathematically as part of a probability of success computation.

Table 2. System Design Considerations

Test Oriented Consideration	Examples	Effect on Test	Effect on System
Command formats	• Standardize on a few, simple formats	• Less processing • Faster processing	• Less flexible • More reliable • More comprehensive test
Telemetry formats/modes	• Avoid data packing • Avoid irregular data organization • Avoid seldom used modes • Maximize commonality between modes	• Less processing • Faster processing	• Less efficient • Less flexible • More reliable • More comprehensive test
Test points	• For higher frequency signals • For telemetry subsystem overflow • For inputs/outputs to external stimuli	• More processing • More visibility • Better troubleshooting capability	• Less reliable • More comprehensive test
Error codes	• For command format faults • For computer status faults • For detected/corrected data errors	• More processing • More visibility • Better troubleshooting capability	• Less reliable unless used as a basis for fault correction

Tables 3 and 4 show specific hardware and software design features which increase a system's testability. Again, these design features can be divided into two major categories:

- Features which impose known inputs or conditions on the system operation, e.g., pattern generators, calibration points, redundancy circuit stimuli, computer self test and software modeling. These features give better visibility and facilitate troubleshooting due to the repeatability and predictability of the results. They, however, only augment the testing and should not be used as a substitute for testing the system with actual data or conditions. Data dependent faults may not be detected without the use of actual data or conditions. Again, the tradeoff between slightly decreased reliability and increased assurance is evident.

- Features which increase visibility or troubleshooting capability, e.g., test points and modifiable telemetry formats. These features are most valuable as troubleshooting aids to obtain an in situ assessment of a potential problem.

Table 3. Hardware Design Considerations

Test Oriented Consideration	Examples	Effect on Test	Effect on System
Pattern generators	• BER checks • Data input simulators	• Predictability • Easier unit/subsystem test • Better trouble-shooting capability	• Less reliable • More comprehensive test
Calibration points	• A/D converter calibration • Radiometer calibration	• Predictability • More visibility • Easier trouble-shooting capability	• Real time accuracy monitoring
Redundancy circuit stimuli (fault simulation)	• Commandable redundancy switching • Data error detection/correction • Initiation of fault tolerant features	• More visibility • Better trouble-shooting capability	• Less reliable • More comprehensive test
Test points	• Test signal inputs • Test signal outputs	• Easier unit/subsystem test • Better trouble-shooting capability	• Less reliable • More comprehensive test
Modifiable telemetry data	• ROM for primary format; RAM for secondary, modifiable formats	• Better trouble-shooting capability	• Less reliable • More flexible

Table 4. Software Design Considerations

Test Oriented Consideration	Examples	Effect on Test	Effect on System
Computer self test	• Memory checks • Instruction execution tests • Addressing mode tests	• More visibility	• Less reliable • More comprehensive test
Software modeling	• Vehicle dynamics simulations • Sensor input simulations	• More processing • Repeatability/predictability	• Less reliable • More comprehensive test
Modifiable telemetry data	• Table driven software telemetry system	• Better trouble-shooting capability	• Less reliable • More flexible

Table 5 summarizes the main issues of this paper. Built-in test features, if considered early in the system design phase, can greatly increase assurance that a system will meet its performance and lifetime requirements. A few generally useful techniques have been presented, however, there are undoubtedly other techniques which can be used for specific system applications – the challenge is to design them in early and make them effective in achieving greater mission assurance.

Table 5. Summary

• Aerospace systems have little internal visibility and are difficult to troubleshoot.
• Factoring in test during system design maximizes visibility and eases troubleshooting.
• Automating test gives repeatability, consistency, and effective data presentation.
• Simple command and telemetry systems maximize testability.
• Both hardware and software are amenable to built in test features.
• Built in test features generally lower conventional (component count) reliability estimates.
• Built in test features increase assurance by more comprehensive testing.

THE DESIGNER/RESPONSIBLE EQUIPMENT ENGINEER'S ROLE IN THE LIFE CYCLE OF SPACE HARDWARE

Mr. Robert C. Koche
Program Manager
Lockheed Missiles and Space Company

We are here to exchange ideas on what it takes to achieve mission success. More specifically, our workshop session addresses "designing for mission assurance". To that end, I would like to talk to a concept that has evolved at Lockheed Missiles and Space Company and which, we think, is a cornerstone of our successes. It is the concept of the Responsible Equipment Engineer.

To me the Designer and Responsible Equipment Engineer (REE) are somewhat synonymous. In our company he is the same in most instances and is the focal point for the design of an equipment item. Even though we may buy equipment from a subcontractor, the Responsible Equipment Engineer is the one held responsible by supervision and management for the proper design, test, and to a major extent, the quality of the hardware. It is the REE who derives equipment performance requirements from the System Specification and translates it into design requirements for the Subcontractor. The REE writes the equipment specification, reviews and approves the related documentation and follows the hardware from the cradle to the grave. In house he may be the man on the board or at the desk who truly is designing every detail of the equipment. When I use the term "equipment", it can mean anything from a solar array module to a guidance black box to a structural frame.

The first slide is an extract from our Policies and Procedures and shows the charter established for "The Responsible Equipment Engineer".

If you will accept the fact that in at least one Aerospace Company, the REEs are the backbone of the design organization; I'll tell you what we expect of them. First, there are certain attributes we think are common to all good REEs. These are inquisitiveness, a good sense of closure, a quickness to bring in specialist support when needed, and be a veritable encyclopedia of knowledge relating to his equipment. We expect the REE to conceive design solutions which meet requirements yet at the same time are simple, cost effective, within the state of art and, hopefully, have small development risks.

The REE interfaces with practically everyone. This next slide shows the range of interfaces. They include System Engineers, Flight Science specialists, Materials and Process specialists, customer, Aerospace, Product Assurance, Manufacturing, test activities, launch pad personnel and even mission support groups. The interfacing may be as little as an occassional presentation to the customer as to how his equipment works, to as much as daily contacts with Reliability, stress analysts, Thermodynamicists, and Product Assurance test technicians. Quite often people think of him as Mr. Horizon Sensor, Attitude Reference Assembly, or some other such name.

We expect the REE to be heavily involved in the birth of his equipment. We expect him to nurse it through the growing pains of breadboarding, prototyping, qualification, first article auditing and then nursing each flight item through each and every ATP failure. Also, we expect him to know how his equipment interfaces with other equipment (or fits in the system), how it is used in flight, its actual flight environment, which performance parameters are critical and which are not. All of this so that he can make the best possible judgment during the design evolution or when evaluating test data. The REE reviews all test data and looks for trends. We expect him to constantly improve test procedures, specification limits and to identify needed design improvements when required. Maybe we even expect him to have a sixth sense to know when to pull his equipment from the satellite vehicle even though it is operating within specification. What we are trying to do is instill a sense of craftsmanship into each of the REEs and to cound on his good judgment to supplement the formal documentation. If we do this, a good part of the battle for mission success is won.

After we achieve this level of performance from one individual, the likelihood is that he will not remain an REE very long. It's these types of engineers that quickly become supervisors, managers and more.

To restate what I've been trying to say is, "Designers or Responsible Equipment Engineers, or whatever you want to call them, of the right caliber, and with a total dedication, are what breed mission success. We must give ample attention to their selection, training, and assignment of responsibilities and authorities."

SSD Policy Directive
(Extract)

A. Policy

SSD organizations having original design responsibility shall assign continuing technical responsibility and authority for thier products or equipment to a "responsible equipment engineer" (REE).

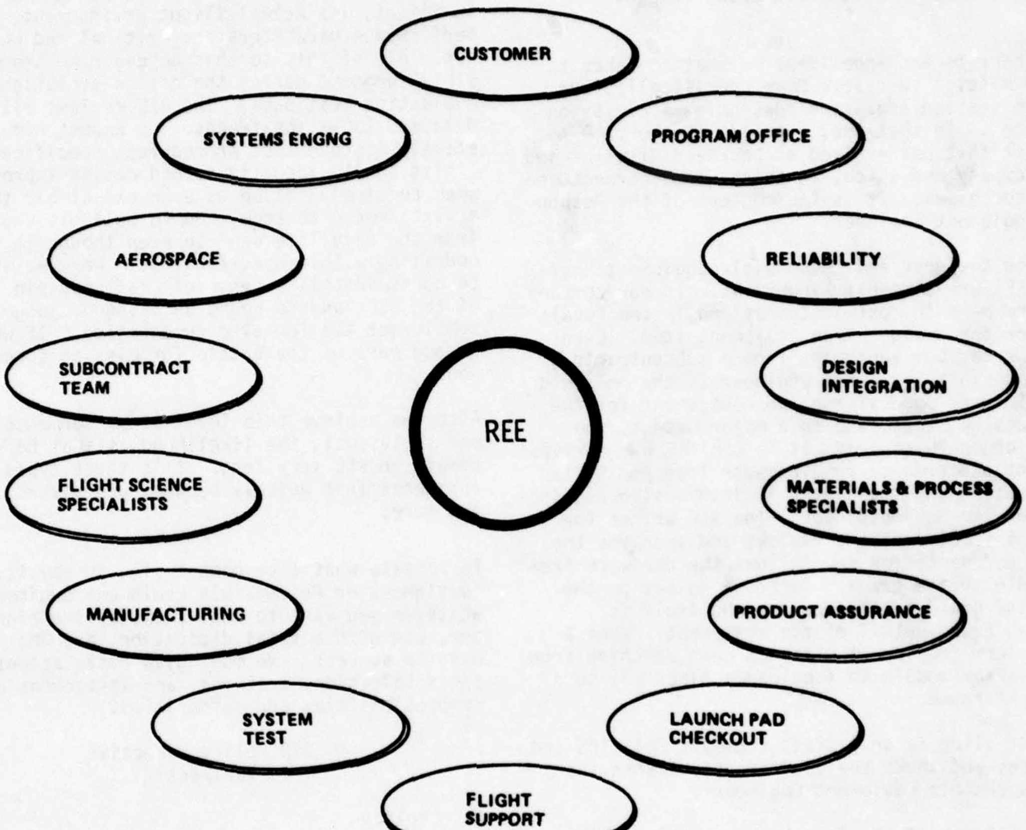
B. Responsibilities

3. Responsible equipment engineers:

A) Establish and document engineering criteria necessary to assure equipment development, design, testing, qualification, production or procurement, and application in response to stated program requirements.

B) Serve as the centralized source of technical information for the assigned product or equipment and the focal point for technical direction or review of all actions pertaining to design, modifications, testing, performance, discrepancies and failures, etc.

WORLD OF THE REE



SPACECRAFT REDUNDANCY

Kenneth P. Timmons
Director, Systems Engineering
Martin Marietta

The application of redundancy to reduce the risk of spacecraft mission loss is a common practice. It should not, however, be added indiscriminately. The intent of this paper is to provide a summary of those factors or considerations which, I believe, have the greatest influence on spacecraft redundancy design. To that end, we will discuss the philosophy which must be established at the very beginning of a spacecraft program to set the stage for us to select an approach to redundancy implementation. Once we have defined and established a philosophy and have settled on an implementation approach, we must employ a methodology which will ensure our meeting system mission goals or requirements within the context of the established philosophy and implementation approach. I will illustrate these processes with some examples from two Martin Marietta designed and built spacecraft, SCATHA (Space Test Program Flight P78-2) and Viking, the Mars Lander vehicle. Lastly, I will discuss the need for and the importance of verifying redundancy prior to the start of a mission along with some typical limitations.

Redundancy Philosophy

The redundancy philosophy to be applied to a given project depends on several factors including: the type of program, for example, a large scale production program such as the Copperhead Laser guided projectile or one-of-a-kind program such as a special satellite; the national priority assigned to the program, the program can range from one of significant scientific importance or critical to national defense to one of relatively minor significance; mission and system characteristics.

The one or two of a kind program usually infers lower acceptable risk just because of the small build quantity where a failure is more likely to end a mission. Redundancy is one of the basic techniques employed to minimize the risk of mission loss. For program having larger build quantities, on the other hand, a failure can be overcome by activating a new item drawn from the production (this is in itself a form of redundancy).

National priorities impact programs by mandating lower mission risk as priority increases. Usually, the higher the priority the more time and money is available to reduce mission risk. This results usually in a more forgivable system design developed by performing more rigorous design analysis, applying greater safety margins and protecting against single failures which would cause the loss of the mission by implementing redundancy.

Mission and system characteristics have great influence on the redundancy philosophy to be employed. For instance an orbiting satellite in a geo-stationary orbit is capable of basically operating and being controlled from the ground in real-time. System performance can be continually monitored and ground commands issued to alter system characteristics, all with little or no transmission delay. The occurence of an anomaly aboard such a spacecraft is usually known by ground operating personnel who can uplink corrective commands in a time span short enough to prevent total loss of the spacecraft. On the other hand, we have the orbital satellite that is out of view of its ground control station for an extended period or the interplanetary spacecraft which is so far from earth that radio transmission require substantial time to travel the great distances involved. The telemetry signal from the Viking Lander on the surface of Mars takes a little more than twenty (20) minutes just to reach the ground stations here on earth. Corrective commands from earth to Mars require an equal amount of time (about 40 minutes total). This is before any interpretation of telemetry or command generation activity is initiated.

Sometimes when delay time or the environment make command impossible, as in the case of the Viking Lander, the spacecraft must be autonomous, that is, it must be capable of independent, fully automatic operation. Conversely, when a spacecraft or satellite is continuously in view of a ground command station, the spacecraft can be dependent, i.e., ground commands may be used to perform all spacecraft control functions. And then there are, of course, combinations of these. Such was the Viking Lander which could either operate autonomously for critical periods such as Martian atmospheric entry or during landed operation or, could be controlled by ground command throughout the landed mission.

The redundancy philosophy then, which involves such considerations as the use of standby block redundancy with automatic failure sensing and switchover to the redundant unit, active block redundancy, majority voting schemes, alternate operating modes, operational work arounds and other techniques to correct or circumvent an anomaly or failure, must be based upon at least the considerations we've just reviewed. Once a redundancy philosophy has been established, the next step is to develop a total system design which reflects the philosophy.

There are at least two basic approaches to redundancy implementation that can be followed once a philosophy is established. The first, and perhaps most common, approach is to set a numerical mission success goal or requirement. Estimated (predicted) system reliability is compared against the numerical goal and, when the initial system design fails to meet the goal or requirement, redundancy is added in accordance with the established philosophy until the goal or requirement is met.

This approach helps to force tradeoffs of the relative value of a number of proposed redundancy additions to achieve maximum reduction of risk for a minimum of other penalties such as weight and cost. The drawback to this approach is that the design is being driven by a numerical goal or requirement that, even if it is achieved, recognizes that a failure could cause the loss of the mission. Risks are reduced but there is no inducement to eliminate critical single failure points which, no matter how low a risk they are, if they should occur would spell the end of the mission. This brings us to the second approach which I call the "NO SINGLE FAILURE" approach. This approach involves the establishment of a "Malfunction Protection Policy" which forces the elimination of all system single point failures through the application of redundancy in accordance with the philosophy established or, requires those single failure points to be

designed for minimum risk by applying stress derating and design margin. The derating and margin would normally be greater when protecting a single failure point than when implemented as a general design criteria.

Ideally, both of these approaches would be implemented. The combination of the two ensures that single point failures are identified and protected. When the protection involves redundancy, the best approach can be identified using a numerical trade-off method to optimize risk reduction as a function of weight, cost or other critical parameters.

Assuming a program implements a malfunction protection policy, the first step in identifying critical single point failures is to perform a failure mode and effects analysis (FMEA) or, what is also termed a failure mode, effects and criticality analysis (FMECA). This analysis should be first performed at the system or major subsystem level and should examine the functional failure modes of each black box or end item. O,casionally, the analysis must go to the functional level in a black box. For dependent spacecraft implementing standby block redundancy with failure detection and command switchover occu-ring on the ground, the functional levels of failure mode analysis are usually adequate. However, when the spacecraft is capable of operating on its own without ground intervention, it is important to take the analysis down to the piece part level. In fact, if a real understanding of failure modes is to be gained, the analysis must go to the functional areas of each integrated circuit chip or hybrid circuit. This is very important since whole ICs don't fail completely most of the time. Frequently, one gate will stick high or low, one bit will be lost in a register, one of two or three line dirvers will fail on or off. This is especially true when the IC has separate power and signal leads for groups of functions contained on the single chip and in a single package.

Following the failure mode analysis, a series of trade studies must be performed. These trade studies are needed to: optimize the design improvement; determine what must really be protected – i.e., can a possible hardware failure more easily be protected by a software or sequence of events change; and lastly, as we have already mentioned, optimize the risk reduction as a function of weight or cost.

Lastly, after the trade studies have been completed there will, no doubt, be some single failure points that do not lend themselves to protection by applying redundancy. Typical of these failure modes are primary structure, propulsive hardware such as lines and fittings or thrust chambers. Frequently complex mechanical hardware such as steerable solar array systems, boom drive assemblies or steerable antenna systems cannot be protected by redundancy due to the high weight or power penalty that must be paid. All of these types of single point failures are then protected by applying an above the normal design safety margin. The same approach applies to electronics except the stress derating would be increased.

Now let us take a brief look at some examples of redundancy implementation. I've chosen the SCATHA (Space Test Program Flight P78-2) orbital satellite and the Mars Viking Lander programs. Both programs have almost identical malfunction protection requirements. The implementation of redundancy, however, is vastly different. The differences are due to mission/system characteristics and national priorities.

The SCATHA mission places the satellite in view of a ground command station most of the time. Communications times are also short which allows almost continuous ground monitoring of spacecraft performance along with the ability to uplink a ground command to correct an anomaly whenever required. The ability to control the satellite in what amounts to real time permitted the application of a redundancy philosophy centered around the concept of standby block redundancy. Exceptions are the command system, which must be continuously accessible, and the experiments. The redundancy implementation approach included a functional FMEA down to the black box level. As a result of this analysis, 20 black box functions were protected by redundancy while four are protected by design margin. All functional black box redundancy is verified prior to mating of the satellite with the payload fairing. Also, provisions are included to automatically save the satellite by removing all non-command critical loads from the power subsystem in the event of an excessive power drain. The system can be reactivated by gound command at which time the anomaly causing the problem can be circumvented by utilizing the available block redundant hardware. Again, this is possible due to basically real time telemetry and command capability.

Before proceeding to the Viking Lander, I want to take just a minute or so to illustrate the actively redundant and cross-strapped command system employed in SCATHA. Both receivers and command decoders are powered on continuously. Both receivers drive both command decoders. Isolation is used at the decoder inputs, for example to prevent a shorting of one input of a decoder from reflecting to and affecting the other decoder. The same is true in the case of any open circuit. No failure of either command receiver or either command decoder will cause the loss of commands or the generation of spurious commands. The cross-strapped receiver/decoder elements drive block redundant command distribution units to provide fully protected command capability.

Now for a discussion of the Viking System. Here we have a system that, because of the extremely long delay in communications coupled with the need to fly a difficult Martian atmospheric entry without ground control, was fully autonomous. A general purpose digital computer controlled the Viking Lander beginning with separation from its orbital mate, through plaentary entry, achieved a soft landing and then performed the landed mission. Because of the fully automatic nature of operation, it was necessary to understand fully the effect of functional failures down to and including functional elements within microcircuits. Therefore the FMEA was performed at the sub piece part level. The redundancy philosophy included the use of active, standby and cooperative redundancy as well as operational workarounds. On Viking, 23 black box functions were protected by redundancy while 28 were protected by design margin. Items protected by margin only are propulsive elements

such as thrust chambers, the aerodecelerator (parachute), the aeroshell and other similar items. In both SCATHA and Viking the experiments themselves were not protected by redundancy. Viking as SCATHA, verified its redundancy at the latest possible point prior to launch and included an onboard capability to save the system in the event of an excessive power drain.

This leaves us with one item that, although we've already touched on it briefly, I would like to emphasize. That is the need to verify whatever redundancy is employed at the latest point possible prior to starting a mission. This is mandatory if the highest confidence is to be achieved in the spacecraft. Of course, there are practical limitations. For example, redundant black boxes can be individua-ly verified only if independent switching is employed to control these boxes. On the other hand, redundancy implemented at the part level, such as parallel fuses, relay contacts, can be verified only prior to installation on the printed circuit board. Once installed, individual access to these parts is usually lost. The key, however, is to verify all redundancy at the latest point possible – don't take it for granted that its there ready to go to work for you.

This completes my discussion on spacecraft redundancy. Thank you for your attention and interest.

Redundancy Philosophy

Depends on:

- Type of program – e.g., large scale production vs one of a kind
- National priority – priority level influences dollars and schedules
- Mission and system characteristics

Redundancy Implementation Approach

- Redundancy employed to meet numerical goal or requirement
    - Forces trade-offs to optimize risk reduction
    - Can permit mission critical failure modes
- Redundancy added in accordance with a "Malfunction Protection Policy"
    - Helps to guarantee that all mission critical failure modes are protected
    - Identifies those failures that can only be protected by means other than redundancy
- Combinations of the above (preferred)

Redundancy Implementation Methodology

- Perform a failure mode and effects analysis*
    - Functional to black box level
    - Functional within a black box
    - Piece part level
    - Functional level within a piece part
- Use trade studies to:
    - Optimize design approach
    - Determine what must really be protected
    - Optimize risk reduction vs weight and cost
- Flat remaining single point failures
    - Justify remaining single point failures
    - Show what technique is used to reduce risk of remaining single point failures

*Depth of FMEA depends on type of spacecraft (i.e., autonomous/dependent)

Redundancy Implementation Examples

SCATHA/Viking Lander

- Both programs have similar requirements:

  "No single point failure shall cause the loss of ..." (SCATHA)

  "No single failure shall cause the loss of ..." (Viking)
- Redundancy implementation was different between programs due to:
    - Mission and system characteristics
    - National priorities

SCATHA

Dependent system – performance is monitored on the ground with redundancy switching by ground command (except for critical command functions).

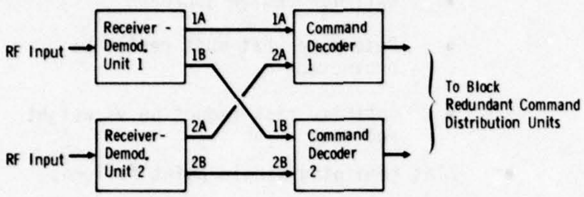
- FMEA performed to functional black box level
- Block redundancy implemented at black box level*
    - 20 black box functions are redundant
    - 4 black box functions are non-non-redundant
    - All redundant black boxes are verified verified prior to mating of spacecraft with payload fairing
- Onboard capability to save the system in the event of excessive power system loading. Ground commands required to correct anomoly.

*All experiments are non-redundant

- Little delay between the transmission and receipt of telemetry data or commands.

Command Receiver Cross-Strapping

No failure of either receiver or decoder will cause the loss of commands or generation of spurious commands.



Viking

Autonomous system — fully automatic control by a general purpose digital computer.

- Very long delay between transmission and receipt of data (20 minutes one way)
- FMEA performed at black box, piece part and sub piece part level
- Active, standby and cooperative redundancy* employed as well as operational workarounds
    - 23 black box functions were redundant
    - 28 black box functions were non-red-ndant
    - All redundant black boxes were verified prior to encapsulating in bioshield and payload fairing mating
- Onboard capability to save the system in the event of excessive power subsystem loading. Ground commands required to correct anomoly.

*All experiments are non-redundant

Redundancy Verification

Redundancy must be verified as close to start of mission as possible if highest confidence is to be achieved.

- Block redundancy should always be tested and verified at black box function level
- Piece part redundancy (e.g., parallel fuses, relay contacts, etc.) usually cannot be verified

WORKSHOP SUMMARY

Design Workshop

Process Description

- 4 Subgroups of 8-12 Attendees Formed
- Design Issues Identified
- Central Themes Compiled
- Recommendations Formulated

Findings/Recommendations

(1) Early, Stable Definition of Requirements

- Review of Draft RFP

(2) Design Review

- Contractor Independent Internal
- Customer DR Not Be For Show
- Aerospace Responsibility Needs Re-Examined
- Improved Software FMEA Methods Needed

(3) Constraints on Resources, Schedule, Cost, Personnel and Performance

- Weighting Factors Needed
- Cost Pressure Significant Detriment

(4) Issue: Continuity of People

- Government Project Officers
- Design Engineering Needed Through Hardware Phase
- Sustaining Engineering Costs
- Motivation for Equipment Engineers

(5) Design Specialists

- Effective Technique for Improving Design for Mission Assurance
- Industry Policies Needed
- Cost Pressures Discourage Implementation.

(6) Design Deficiencies Major Cause of Catastrophic Failure

- Emphasis Required in Design Process

  Interdisciplinary Skills
- Continuing Independent Design Examination
- Electromechanical, Mechanical Assemblies Primary Source of Design Problems

  Critical Item Control Needed

(7) Launch of Prototype Spacecraft/Hardware

- Cheap Ride (Shuttle)
- Recovery
- Failure Detection/Correction Prior to Operational Deployment
- Check Out Prior to Transfer Orbit
- Test Article Characteristics

Conclusion: Establish SAMSO/Industry Panel to Examine Relative Merits

(8) Reliability Analysis Most Beneficial Technique

- Current Programs Generally Satisfactory
- Extend to Mechanical, Electromechanical, Hydraulics and Software
- Application to Older Hardware
- Extend FMEA to Manufacturing, Test and Mission Analysis Phases

Other Items

- Failure Data Base Dissemination
- MIL STDS/Specs — Discussion Forum

DESIGN FOR MISSION ASSURANCE

QUESTIONNAIRE

(32 Respondents)

		Yes	No	No Opinion
1.	Are environmental criteria/requirements over-specified?	11/ 34%	17/ 53%	4/13%
2.	Are design/development schedules adequate?	7/ 23%	22/ 69%	3/8%
3.	Is the current system for defining booster weight-lifting capability adequate?	12/ 38%	2/ 6%	18/56%
4.	Should the hardware designer be involved in manufacture and test?	30/ 94%	2/ 6%	0
5.	Are adequate provisions for testability incorporated in design?	12/ 38%	17/ 54%	3/8%
6.	Should formal product design reviews constrain design release?	25/ 79%	3/ 8%	4/13%
7.	Is AGE compatibility with flight hardware adequately reviewed?	8/ 25%	19/ 59%	5/16%
8.	Does inability to test flight hardware for difficult environments engender excessive risk?	15/ 47%	13/ 40%	4/13%
9.	Is risk identification and management properly implemented?	10/ 31%	18/ 56%	4/13%
10.	Is adequate emphasis placed on Electrical/Mechanical AGE design?	8/ 25%	18/ 56%	6/19%
11.	Does use of redundancy decrease emphasis on good design?	9/ 29%	20/ 63%	3/8%
12.	Are drawing releases demanded too early in a program?	15/ 47%	12/ 37%	5/16%
13.	Are design changes effectively screened and controlled?	18/ 56%	13/ 41%	1/3%
14.	Are design performance budgets worth their upkeep?	21/ 66%	2/ 6%	9/28%
15.	Is adequate attention paid to interface definition and control?	20/ 63%	8/ 25%	4/12%
16.	Should the prime contractor exercise more control of sub-contractors' design/development activities?	23/ 71%	7/ 23%	2/6%
17.	Are hardware designers sufficiently versed in orbital operations?	7/ 23%	19/ 59%	6/18%
18.	Should more emphasis be placed on test in lieu of analyses for performance verification?	19/ 59%	9/ 28%	4/13%
19.	Are performance requirements by the Government over-specified?	12/ 37%	13/ 40%	7/23%
20.	Are structural design margin requirements (margins of safety) excessive?	0	20/ 63%	12/37%
21.	Should FMEA incorporate sneak path analysis?	25/ 79%	1/ 3%	6/18%
22.	Do you use a preferred parts list?	28/ 88%	2/ 6%	2/6%

QUESTIONNAIRE

		Yes	No	No Opinion
23.	Is the parts selection process overly restrictive of your design?	2/ 6%	25/ 79%	5/15%
**24.	What percentage of the parts selected by your normal process prove to be "poor" parts?	10/ 31%	2/ 6%	20/63%
25.	Is your current parts selection process cost effective?	15/ 46%	7/ 23%	10/31%
26.	In your personal experience, are part failures a principal cause of mission failures?	19/ 60%	10/ 31%	3/9%
27.	In your own personal experience, are failures due to part misapplication an important part of mission failure?	14/ 44%	13/ 40%	5/16%
28.	Do you use reliability prediction as a portion of your design process?	25/ 78%	5/ 16%	2/6%
29.	Does your reliability prediction work encompass stress derating?	24/ 75%	4/ 12-1/2%	4/12-1/2%
30.	Do you use a failure modes effects and criticality analysis in your design process?	28/ 88%	2/ 6%	2/6%
31.	Is the failure modes analysis effective in identifying redundancy requirements, single point failure modes, or other design weaknesses?	22/ 69%	4/ 13%	6/18%
32.	Have you experienced mission failure due to single point failure modes that were identified during the design process?	6/ 18%	22/ 69%	4/13%
33.	Have you experienced mission failure due to previously unidentified single point failure modes?	10/ 31%	17/ 53%	5/16%
34.	Are you satisfied with your current design review practices?	12/ 37%	16/ 50%	4/13%
35.	Is the customer's participation in your design review beneficial?	25/ 79%	3/ 8%	4/13%
36.	Do you use a formal failure analysis and correction action program?	27/ 84%	3/ 8%	2/6%
37.	Is your failure analysis and corrective action program effective in preventing failures of a similar kind?	26/ 84%	3/ 8%	3/8%
38.	Are you satisfied with your current design change evaluation techniques?	18/ 56%	13/ 41%	1/3%
39.	Have you had mission failures due to poor change evaluation?	5/ 16%	24/ 75%	3/9%
40.	Are you satisfied with the translation of design data to manufacturing instructions?	9/ 28%	19/ 60%	4/12%
41.	Are you satisfied with your current design techniques for moving mechanical assemblies?	12/ 37-1/2%	12/ 37-1/2%	8/25%
42.	Have you experienced mission failure of a moving mechanical assembly?	17/ 53%	14/ 44%	1/3%
43.	Are you satisfied with your current thermal design techniques?	17/ 53%	11/ 34%	4/13%
44.	Have you experienced a mission failure due to thermal design?	6/ 69%	22/ 18%	4/13%

QUESTIONNAIRE

		Yes	No	No Opinion
45.	Are you satisfied with your current material and process selection and application techniques?	21/ 66%	10/ 31%	1/3%
46.	Have you experienced problems due to differences between government/industry interpretation of design requirements?	25/ 79%	6/ 18%	1/3%
47.	Are you satisfied with the FCRC (Aerospace, Mitre, et al) role in your design?	8/ 25%	15/ 47%	9/28%
48.	Does your company or organization utilize a special motivation, recognition or incentive program to enhance mission assurance?	12/ 38%	14/ 44%	6/18%

	Yes	No	No Opinion
**24.	5%		Very few
	1%		Less than 1%
	10%		20%
	5%		10%
	<1%		<1%
	10%		5%
		5 - 10%	
	30%		
	<2%		

Actual percentages given on some papers

WORKSHOP B

THE ROLE OF CONTRACTUAL INCENTIVES IN MANAGEMENT MOTIVATION FOR MISSION ASSURANCE

Co-Chairmen

Lt. Col. Kenneth JuVette
Director of Procurement
Space Navigation Systems
SAMSO/PMN

Mr. Robert H. Crotser
Deputy Program Manager
Space Systems Div.

Mr. Richard M. Randall
Director, Business Management
McDonnell Douglas

Coordinator

Maj. Robert Dalrymple
Asst. Director of Procurement,
Space, Comm., SAMSO

AGENDA

Wednesday, April 26

0830-0900	Introduction	Lt. Col. Kenneth JuVette, SAMSO
0900-0920	Review of Contract Types	Mr. Robert H. Crotser, Lockheed, LMSC
0920-0940	The Value of Incentives	Mr. Patrick R. McGinnis, McDonnell Douglas
0940-1000	Break	
1000-1130	Are Incentives Useful to Achieve MIssion Success	Mr. Harold E. Sharp, SAMSO Mr. Grant Hansen, SDC Mr. Robert J. Ingersoll, Boeing Aircraft Co.
1130-1200	Open Forum	
1200-1245	Lunch	
1245-1415	Organizational Effect of Administering Incentives	Mr. Hubbert L. O'Brien, TRW Inc. Col. John J. Caulfield, SAMSO Mr. George S. Pappas, Ball Brothers
1415-1430	Break	
1430-1530	Incentive Innovations	Lt. Col. Michael M. McMillan, HQ AFSC Mr. P. Nino Noal, Hughes Aircraft Co.
1530-1630	Open Discussion	

INTRODUCTION

Lt Col Kenneth JuVette
Director of Procurement
Space Navigation Systems
SAMSO/PMN

Lt Col JuVette welcomed the approximately fifty attendees and presented a series of viewgraphs giving the background and highlights of the SAMSO/Industry Executive Session on Mission Assurance as it addressed Contractual Incentives. His presentation also included a series of unattributed quotes from letters to General Morgan written by industry representatives. Specific mention was made of some Air Force Lessons Learned in the area of Award Fee and of the Air Force Systems Command Initiative No. 13 to: Develop Innovative Procedures to Motivate Contractors to Improve Weapon Systems Performance In the Field.

The Workshop speakers and topics were introduced to the audience. We were all challenged by Lt Col JuVette in his closing remarks to identify counterproductive policies, actions, and practices, and to make recommendations for improving the Mission Success of our space and missile programs.

Workshop Schedule

0830-0900	Introduction	Lt Col Ken JuVette
0900-0920	Review of Contract Types	Mr. Bob Crotser Deputy Program Manager Lockheed Missiles & Space Co.
0920-0940	The Value of Incentives	Mr. Dick Randall Director of Business Management, McDonnell Douglas Astronautics Co.
0940-1000	Break	
1000-1130	Are Incentives Useful?	Mr. Hal Sharp Chief, Pricing Office Mr. Grant Hansen President SDS Systems Group Bob Ingersoll, Boeing Contracts Manager Missiles and Space Division
1130-1200	Open Forum	
1200-1245	Lunch	
1245-1415	Organizational Effect of Administering Incentives	Mr. Hub O'Brian TRW, Manager of Contracts, Space Systems Division Col Jack Caulfield Director of Procurement for Space Communication Systems Mr. George Pappas Ball Brothers, Director of Contracts
1415-1445	Forum	
1445-1500	Break	
1500-1600	Incentive Innovations	Lt Col Mike McMillan AFSC, Procurement and Manufacturing Mr. Nino Noal Manager of Contracts Defense Systems Division, Hughes
1600-1630	Open Forum	

Question??

Is the present role of contractual incentives a positive or negative force in the attainment of mission success?

Background on Workshop

- Meetings were held during 1977 with SAMSO commander and key industry executives.
- Leaders collectively identified a wide range of key elements critical to mission success.
- Three industry associations accepted along with SAMSO to explore issues in greater detail.
- Contractual incentives identified as a key area to control risk through improved management.

Additionally – Air Force systems command has established a command initiative No. 13 to:

Develop innovative procedures to motivate contractors to improve weapon systems performance in the field.

Also – Prime and subcontractors are continually addressing the subject of incentives, motivation, and mission assurance.

Highlights of SAMSO/Industry Executive Session On Mission Assurance – Incentives

- Performance oriented incentives significantly greater than cost or schedule are considered a strong tool for focusing management attention on those areas that enhance the probability of mission success.
- Properly drawn, incentives could be the guide for every management decision and trade-off in deciding how and where to apply resources.
- Achieving the appropriate balance of contract incentives is considered very important in motivating contractor management in the right direction.

- Several examples of how incentives can actually contribute to failures, anomalies and performance degradation were given.

- Timing of incentive payments is also important to maximize the motivation desired.

- Contract incentives can be used by management to motivate personnel to avoid practices that might inadvertently degrade the product. Incentives should be passed down to the first line supervisors or lower in "real time."

- Both parties should have a clear understanding of the incentive structure before starting work. Rules should be published in advance. Also, there should be no conflict between incentives, i.e., cost schedule vs. performance.

- The subject of personnel motivation could be closely associated with contract incentives.

- Using the incentive resources to reward personnel performance, and getting it passed on to the man or woman on the bench, is a very important aspect of mission assurance.

- Some attendees felt that multi-year on-orbit performance incentives that are paid downstream are not effective. The performance of contract personnel is graded in the present, not in the future.

- Early payment of incentives when initial performance is achieved is effective. We might consider the use of incentives in the front end of the program and assess penalties if full performance is not attained.

- Award fees, properly structured and operated, are a good management tool. Both parties should have commonality of purpose and mutual understanding of the award fee plan.

AWARD FEE
Some USAF Lessons Learned

- R&D contracts: Award fee should be used with caution in such cases since the incentivizing of administrative features (cost, timeliness of reports, etc.) may cause the contractor to emphasize these areas at the expense of the R&D effort.

- Contracts with a high proportion of labor cost were successfully utilizing award fee where the award fee was passed on to the employees by the contractor.

- The decision to use award fee provisions should balance the potential for improved contractor performance against the administrative cost and effort which will be required to support the award fee.

- All the motivators likely to affect the contractor must be considered in making the decision to use award fee. As an example, if the successful accomplishment of a particular contract will result in a large production follow-on, the contractor may be so motivated by such a situation that award fee would not be necessary.

- In a recent USAF acquisition study a questionnaire of industry on various procurement practices revealed their unanimous favor of award fees. There are two main reasons for this:

  - The contractor liked the "Report Card" and found it was to be extremely useful to his program manager.

  - It was a means of forcing strong communication links between contractor and Government.

Industry Viewpoints Expressed To SAMSO Commander

- "...I have puzzled as to whether or not there might be more effective incentives for contractors."

- "...I know some of the problems in trying to design a financial incentive package which pays off to the people whom you really wish to motivate."

- "The most powerful incentive is that for future contracts, rather than profit."

  "Increased use should be made of flight performance incentives with greater rewards and penalties provided."

  We would also recommend re-establishing substantial flight performance incentives on current and future programs. I am convinced that this type of incentive tends to focus and discipline the management attention which is vital to mission success.

- "Contractual orbital performance incentives which are greater than cost and schedule incentives make it very clear to the contractor that performance is the most important factor to the space customer."

- "With strong performance incentives, a contractor is more likely to balance schedule and cost performance to take actions which the contractor's program manager believes will significantly increase the probability of earning improved performance incentives."

- "Fixed price contracts to the prime, and from the prime to the subcontractors are not conducive to high quality products in many cases. More creative incentive procurement effort is desirable."

- "Executive management participation could be encouraged by including incentives in the contract for performance, using the

performance records as part of the incentive criteria for future contracts, and publicizing when a good product is produced.

- "If performance is desired, place the significant <u>incentive on mission performance</u>."

- "Judge both the Air Force team and the Contractor teams on whether the incentive is paid in full for full achievement, partially paid for mediocrity, or no incentive for failure."

- "The performance incentive is a strong tool for focusing management attention; it likewise could be an appropriate gauge for grading the Air Force team and focusing their attention."

- "If the performance incentive provision is appropriately drawn, then it forms the guide for every management and technical decision, i.e., how does each particular decision or course of action affect the attaining of the performance fee?"

<u>The Challenge</u>

Mission success is the overriding goal of SAMSO/Aerospace/Contractor teams.

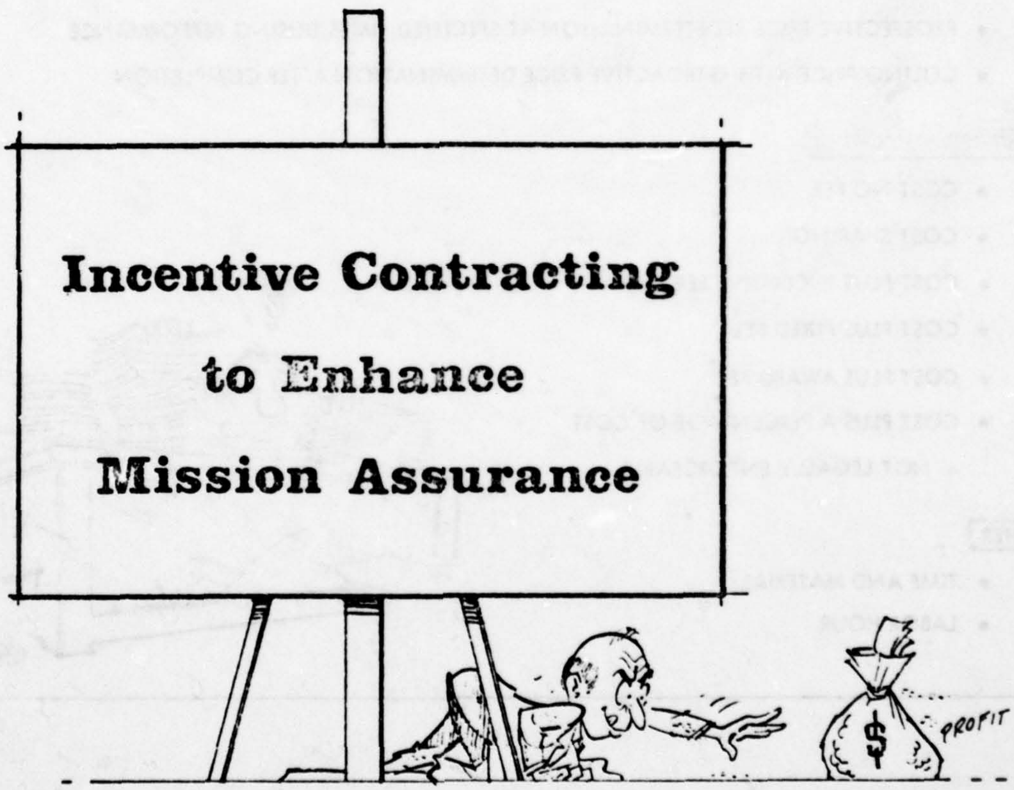
- Any actions, policies or practices that tend to defer from obtaining this objective are suspect.

- Effort is continuing at identifying and changing management practices that are considered counter productive to achievement of mission success.

REVIEW OF CONTRACT TYPES

Mr. Robert H. Crotser
Deputy Program Manager
Space Systems Division
Lockheed Missile and Space Corp.

Mr. Crotser presented a series of cleverly cartooned viewgraphs in a capsule course on contract types and considerations. He demonstrated how the choice of contract types is a function of risk and provided some basic principles and factors to be considered when selecting a contract type. Mr. Crotser provided a description and application for all the contract types and gave some personal observations in the incentive area. Mr. Crotser mentioned the use of the "Martin Incentive" (a form of incentive payment where the total performance fee is paid to the contractor upon delivery and the contractor must pay back to the Government any amount lost for less than nominal performance during operation) and stated that he expects to see more CPIF/AF (combination incentive fee and award fee) contracts in the future. Mr. Crotser favors an award fee contract in which the award fee criteria can be changed on a period-to-period basis.



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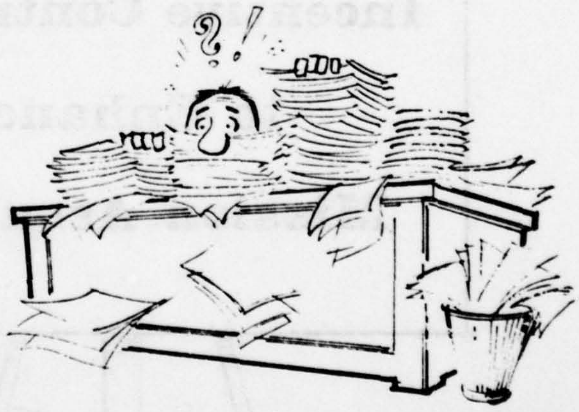
TYPES OF CONTRACTS

FIXED PRICE

- FIRM FIXED PRICE
- FIXED PRICE WITH ESCALATION PROVISIONS
- FIXED PRICE INCENTIVE
- PROSPECTIVE PRICE REDETERMINATION AT SPECIFIED TIMES DURING PERFORMANCE
- CEILING PRICE WITH RETROACTIVE PRICE DETERMINATION AFTER COMPLETION

COST REIMBURSEMENT

- COST NO FEE
- COST SHARING
- COST PLUS INCENTIVE FEE
- COST PLUS FIXED FEE
- COST PLUS AWARD FEE
- COST PLUS A PERCENTAGE OF COST
  - NOT LEGALLY ENFORCEABLE



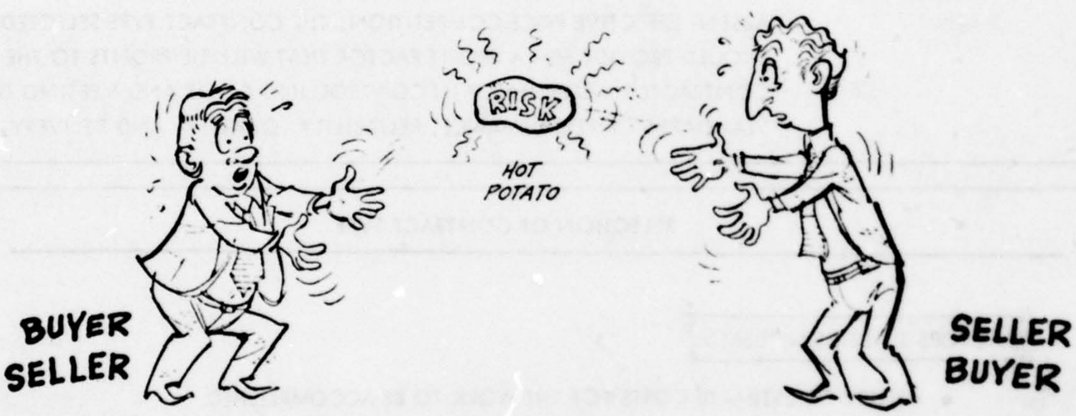
OTHER

- TIME AND MATERIAL
- LABOR HOUR

METHOD OF CONTRACTING

– A FUNCTION OF RISK –

HIGH		MEDIUM		LOW
FFP	⟷	FPI ⟷ CPIF	⟷	CPFF



SELECTION OF CONTRACT TYPE

BASIC PRINCIPLES

- PROFIT, GENERALLY, IS THE BASIC MOTIVE OF THE BUSINESS ENTERPRISE.
- THE CONTRACTING PARTIES SHOULD SEEK TO NEGOTIATE AND USE THE CONTRACT TYPE BEST CALCULATED TO STIMULATE OUTSTANDING PERFORMANCE
  - <u>OBJECTIVE:</u> CONTRACT TO ENSURE THAT EFFECTIVE AND ECONOMICAL PERFORMANCE IS MET BY HIGH PROFITS, MEDIOCRE PERFORMANCE BY MEDIOCRE PROFITS, AND POOR PERFORMANCE BY LOW PROFITS OR LOSSES.
- WHERE EFFECTIVE PRICE COMPETITION IS FEASIBLE, THERE IS REASONABLE ASSURANCE THAT THE CONTRACT PRICE REPRESENTS A REALISTIC PRICING STANDARD, INCLUDING A PROFIT FACTOR WHICH REFLECTS AN APPROPRIATE RETURN TO THE CONTRACTOR FOR THE FINANCIAL RISK ASSUMED IN UNDERTAKING PERFORMANCE AT THE COMPETITIVE PRICE.
- ABSENT EFFECTIVE PRICE COMPETITION, THE CONTRACT TYPE SELECTED SHOULD PROVIDE FOR A PROFIT FACTOR THAT WILL TIE PROFITS TO THE CONTRACTOR'S EFFICIENCY IN CONTROLLING COSTS AND MEETING DESIRED STANDARDS OF PERFORMANCE, RELIABILITY, QUALITY, AND DELIVERY.

SELECTION OF CONTRACT TYPE

FACTORS TO BE CONSIDERED:

- ABILITY TO ESTIMATE COSTS FOR THE WORK TO BE ACCOMPLISHED
  - UNCERTAINTIES IN TECHNOLOGY
  - TYPE AND COMPLEXITY OF ITEM/PERFORMANCE CONTRACTED FOR
  - STABILITY OF DESIGN
  - PERIOD OF PERFORMANCE
  - CONTRACTOR EXPERIENCE WITH SIMILAR PROCUREMENTS
  - ADEQUACY OF CONTRACTOR'S ESTIMATING SYSTEM
- URGENCY OF REQUIREMENT
- ADEQUACY OF CONTRACTOR'S ACCOUNTING SYSTEM
- TYPE AND SIMILARITY WITH CONTRACTOR'S CONCURRENT CONTRACTING EFFORTS

EFFECTIVE COST ESTIMATING

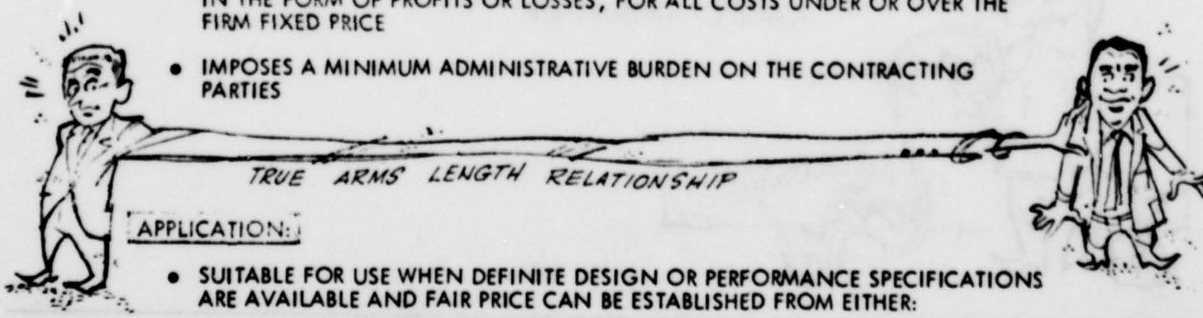
– A MUST TO INCENTIVE CONTRACTING –

CONTRACTOR

FIRM FIXED PRICE CONTRACT

DESCRIPTION:

- PRICE IS NOT SUBJECT TO ANY ADJUSTMENT BY REASON OF THE COST EXPERIENCE OF THE CONTRACTOR IN THE PERFORMANCE OF THE CONTRACT
- PLACES MAXIMUM RISK ON CONTRACTOR – ASSUMES FULL RESPONSIBILITY IN THE FORM OF PROFITS OR LOSSES, FOR ALL COSTS UNDER OR OVER THE FIRM FIXED PRICE
- IMPOSES A MINIMUM ADMINISTRATIVE BURDEN ON THE CONTRACTING PARTIES



APPLICATION:

- SUITABLE FOR USE WHEN DEFINITE DESIGN OR PERFORMANCE SPECIFICATIONS ARE AVAILABLE AND FAIR PRICE CAN BE ESTABLISHED FROM EITHER:
  - ADEQUATE PRICE COMPETITION
  - PRIOR PURCHASE HAVE BEEN MADE OF SAME OR SIMILAR ITEMS SUPPORTED BY VALID COST OR PRICING DATA
  - COST OR PRICING DATA IS AVAILABLE UPON WHICH REALISTIC ESTIMATES OF THE PROBABLE COSTS OF PERFORMANCE CAN BE MADE
  - IDENTIFICATION OF THE UNCERTAINTIES OF PERFORMANCE AND ASSOCIATED RISKS WITH ADEQUATE MEANS AVAILABLE TO PRICE SAME
- NORMALLY USED FOR STANDARD OR MODIFIED COMMERCIAL ITEMS OR LOW TO MEDIUM TECHNOLOGY ITEMS WHERE DEVELOPMENT IS COMPLETE AND PRODUCTION EXPERIENCE IS AVAILABLE TO SUPPORT PRICING.

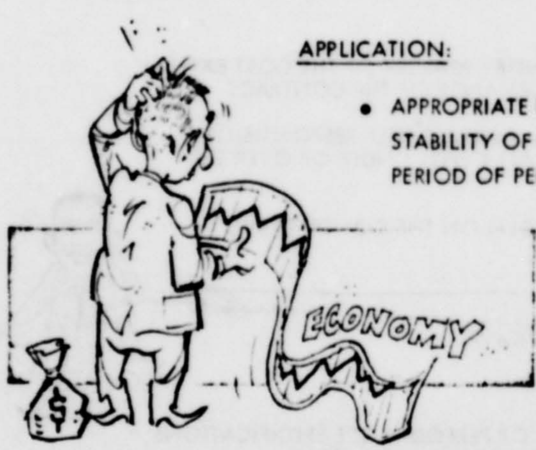
FIXED PRICE CONTRACT WITH ESCALATION

DESCRIPTION:

- PRICE IS SUBJECT TO UPWARD AND/OR DOWNWARD REVISION UPON THE OCCURRENCE OF SPECIFICALLY DEFINED ECONOMIC CONTINGENCIES
  - NORMALLY RELATED TO LABOR AND MATERIAL COST WITH ADJUSTMENT BASED ON FORMULA, ECONOMIC INDICES, OR CHANGES TO PUBLISHED PRICING
  - NORMALLY INCLUDES NOT-TO-EXCEED CEILING PRICE

APPLICATION:

- APPROPRIATE FOR USE ONLY WHEN SERIOUS DOUBT EXISTS AS TO THE STABILITY OF MARKET OR LABOR CONDITIONS OVER AN EXTENDED PERIOD OF PERFORMANCE



FIXED PRICE INCENTIVE CONTRACTS

DESCRIPTION:

- CONTRACT PROVIDES FOR A NEGOTIATED TARGET COST, TARGET PROFIT, TARGET PRICE, AND A CEILING PRICE (BUT NOT A PROFIT CEILING OR FLOOR) AND A FORMULA FOR ESTABLISHING FINAL PROFIT AND PRICE
  - INCENTIVE FEE STRUCTURE CAN PROVIDE FOR PROFIT ADJUSTMENT BASED ON COST PERFORMANCE ONLY OR CAN INCLUDE ADDITIONAL ADJUSTMENT FACTORS FOR SCHEDULE AND OPERATIONAL PERFORMANCE
  - FIRM TARGETS
  - SUCCESSIVE TARGETS (INITIAL TARGET PRIOR TO FIRM TARGET WITH FORMULA ADJUSTMENT)
  - NEGOTIATED INTERIM BILLING PRICE OR PROGRESS PAYMENTS MAY SERVE AS BASIS FOR PAYMENT WITH EXTENDED PERIOD OF PERFORMANCE

APPLICATION:

- USE WHEN FFP IS NOT FEASIBLE BUT CIRCUMSTANCES ARE OF SUCH A NATURE THAT ASSUMPTION OF A DEGREE OF COST RESPONSIBILITY PROVIDES THE CONTRACTOR WITH A POSITIVE PROFIT INCENTIVE FOR EFFECTIVE COST AND PERFORMANCE CONTROL
  - HIGHER RISK TO CONTRACTOR THAN CPIF DUE TO CEILING PRICE
- REQUIRES ADEQUATE CONTRACTOR ACCOUNTING SYSTEM FOR TRACKING AND AUDIT OF ALLOWABILITY AND ALLOCABILITY OF COSTS
- SUCCESSIVE TARGETS ONLY USED WHEN INITIAL COST AND PRICING DATA IS INSUFFICIENT TO PERMIT REALISTIC FIRM TARGETS

FIXED PRICE REDETERMINABLE CONTRACT

DESCRIPTION:

- PROVIDES FOR A FIRM FIXED PRICE FOR INITIAL PERIOD OF PERFORMANCE AND FOR PROSPECTIVE PRICE REDETERMINATION (UPWARD OR DOWNWARD) FOR SUBSEQUENT PERIODS OF PERFORMANCE
  - A SERIES OF FFP CONTRACTS
  - NORMALLY INCLUDES A CEILING PRICE FOR THE TOTAL PERIOD OF PERFORMANCE SO CONTRACTOR ASSUMES A MAJOR PORTION OF RISK

APPLICATION:

- WHERE THE FAIRNESS OF REASONABLENESS OF A FFP IS TIME ORIENTED AND CAN ONLY BE ESTABLISHED FOR AN INITIAL PERIOD BUT NOT FOR SUBSEQUENT PERIODS
- CONTRACTOR'S ACCOUNTING SYSTEM MUST BE ADEQUATE FOR PRICE REDETERMINATION PURPOSES
- REQUIRES TIMELY PRICE REDETERMINATION

RETROACTIVE FIXED PRICE DETERMINATION CONTRACT

DESCRIPTION:

- PROVIDES FOR A CEILING PRICE AND RETROACTIVE PRICE REDETERMINATION AFTER COMPLETION OF THE CONTRACT
  - BASIS FOR PRICE REDETERMINATION SHOULD BE PRE-ESTABLISHED AND SHOULD NORMALLY EMPHASIZE MANAGEMENT EFFECTIVENESS AND INGENUITY DURING PERFORMANCE

APPLICATION:

- WHERE FAIR AND REASONABLE PRICE CANNOT BE NEGOTIATED FROM OUTSET AND OTHER TYPES OF CONTRACTS ARE IMPRACTICABLE
- NORMALLY SMALL VALUE (UNDER $100,000) AND SHORT PERIOD OF PERFORMANCE (LESS THAN SIX MONTHS)
- CEILING PRICE SHOULD IMPOSE SOME DEGREE OF RISK ON CONTRACTOR
- REQUIRES ADEQUATE ACCOUNTING SYSTEM FOR PRICE REDETERMINATION PURPOSES
- PRICE REDETERMINATION SHOULD BE TIMELY
- CANNOT BE COST-PLUS-A-PERCENTAGE-OF-COST

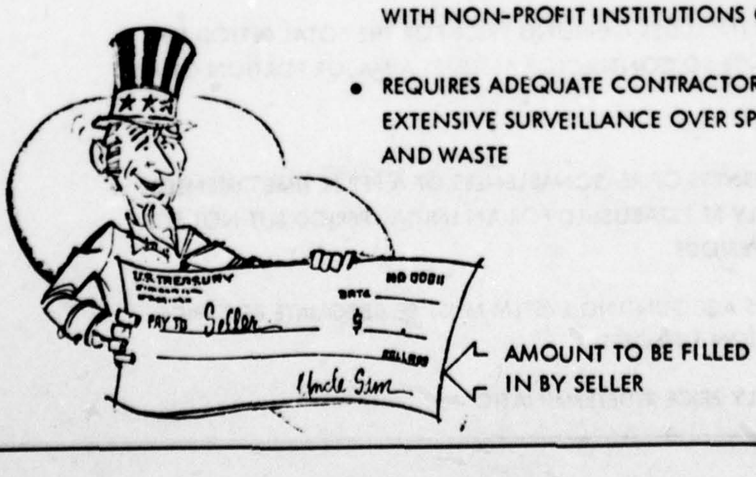
COST, NO FEE CONTRACT

DESCRIPTION:

- PROVIDE FOR THE PAYMENT TO THE CONTRACTOR ALL ALLOWABLE AND ALLOCABLE COSTS INCURRED IN THE PERFORMANCE OF THE CONTRACT BUT NO FEE

APPLICATION:

- NORMALLY ONLY USED FOR RESEARCH AND DEVELOPMENT WORK WITH NON-PROFIT INSTITUTIONS OR ORGANIZATIONS
- REQUIRES ADEQUATE CONTRACTOR ACCOUNTING SYSTEM AND EXTENSIVE SURVEILLANCE OVER SPENDING TO AVOID INEFFICIENCY AND WASTE



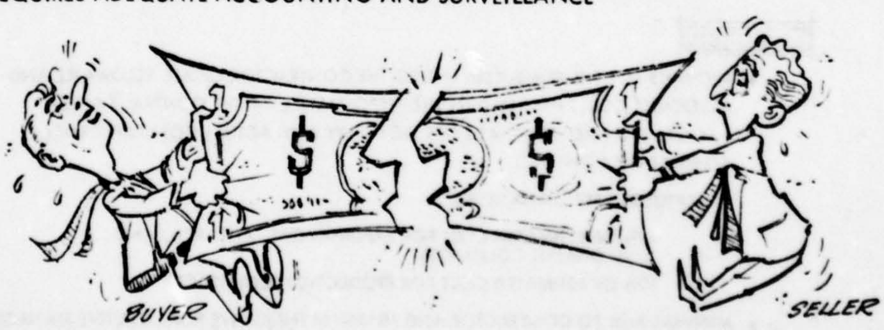
COST SHARING CONTRACT

DESCRIPTION:

- A COST REIMBURSEMENT TYPE CONTRACT UNDER WHICH THE CONTRACTOR RECEIVES NO FEE AND IS REIMBURSED ONLY FOR AN AGREED PORTION OF HIS ALLOWABLE AND ALLOCABLE COSTS

APPLICATION:

- JOINTLY SPONSORED PROJECT WHERE IT IS AGREED THAT THE CONTRACTOR RECEIVES A SUFFICIENT COMMERCIAL OR OTHER BENEFIT THAT HE SHOULD ABSORB A PORTION OF THE COSTS OF PERFORMANCE
  - E.G.: DEVELOPING A TECHNOLOGICAL CAPABILITY THAT HAS A SIGNIFICANT FUTURE SALES POTENTIAL
- REQUIRES ADEQUATE ACCOUNTING AND SURVEILLANCE



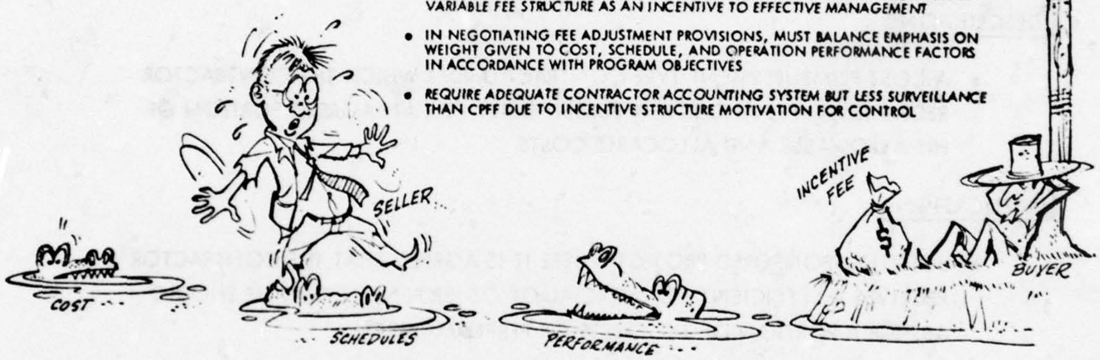
COST – PLUS – INCENTIVE FEE CONTRACT

DESCRIPTION:

- A COST REIMBURSEMENT CONTRACT WHERE THERE IS INITIALLY NEGOTIATED A TARGET COST, A TARGET FEE, A MINIMUM AND MAXIMUM FEE, AND A FEE ADJUSTMENT FORMULA NORMALLY BASED UPON ACTUAL COST, SCHEDULE, AND OPERATIONAL PERFORMANCE
  - CONTRACTOR IS PAID ALL ALLOWABLE AND ALLOCABLE COSTS INCURRED IN THE PERFORMANCE OF THE CONTRACT AND A FINAL FEE IN ACCORDANCE WITH THE NEGOTIATED TARGET FEE ADJUSTMENT PROVISIONS OF THE CONTRACT
  - INTERIM BILLING FEE IS NEGOTIATED AND INCLUDED IN THE CONTRACT
- THE PROVISION FOR INCREASE OR DECREASE IN THE FEE (USING TARGET FEE AS THE BASELINE) IS DESIGNED TO PROVIDE AN INCENTIVE FOR MAXIMUM EFFORT ON THE PART OF THE CONTRACTOR TO MANAGE THE CONTRACT PERFORMANCE EFFECTIVELY

APPLICATION:

- USED PRIMARILY FOR FEASIBLE DEVELOPMENT AND TEST TYPE CONTRACTS WHERE PERFORMANCE PARAMETERS ARE DEFINED AND THERE IS A HIGH PROBABILITY THEY CAN BE ACHIEVED AND IT IS ADVISABLE TO PROVIDE THE CONTRACTOR WITH A VARIABLE FEE STRUCTURE AS AN INCENTIVE TO EFFECTIVE MANAGEMENT
- IN NEGOTIATING FEE ADJUSTMENT PROVISIONS, MUST BALANCE EMPHASIS ON WEIGHT GIVEN TO COST, SCHEDULE, AND OPERATION PERFORMANCE FACTORS IN ACCORDANCE WITH PROGRAM OBJECTIVES
- REQUIRE ADEQUATE CONTRACTOR ACCOUNTING SYSTEM BUT LESS SURVEILLANCE THAN CPFF DUE TO INCENTIVE STRUCTURE MOTIVATION FOR CONTROL



COST – PLUS – FIXED FEE CONTRACT

DESCRIPTION:

- PROVIDES FOR THE REIMBURSEMENT TO THE CONTRACTOR OF ALL ALLOWABLE AND ALLOCABLE COSTS INCURRED IN THE PERFORMANCE OF THE CONTRACT AND A NEGOTIATED FIXED FEE THAT DOES NOT VARY WITH ACTUAL COST EXPERIENCE AGAINST THE CONTRACT
  - STATUTORY FEE LIMITATIONS:

    15% OF ESTIMATED COST FOR EXPERIMENTAL, RESEARCH, AND DEVELOPMENT CONTRACTS

    10% OF ESTIMATED COST FOR PRODUCTION CONTRACTS
- MINIMAL RISK TO CONTRACTOR AND MINIMUM INCENTIVE FOR EFFECTIVE MANAGEMENT CONTROL OF COSTS

APPLICATION:

- NORMALLY USED IN RESEARCH, STUDY, OR DEVELOPMENT CONTRACTS INVOLVED WITH ADVANCING THE STATE-OF-THE-ART WHERE SIGNIFICANT UNKNOWNS EXIST WITH RESPECT TO THE LEVEL OF EFFORT REQUIRED FOR PERFORMANCE, SOME FEE IS DETERMINED TO BE JUSTIFIED, AND A CPIF CONTRACT IS DETERMINED NOT TO BE FEASIBLE
- REQUIRES ADEQUATE CONTRACTOR ACCOUNTING SYSTEM AND EXTENSIVE SURVEILLANCE OVER SPENDING TO AVOID INEFFICIENCY AND WASTE

COST – PLUS – AWARD FEED CONTRACT

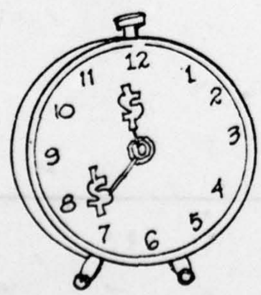
DESCRIPTION:

- CONTRACTOR'S FEE IS DETERMINED SUBJECTIVELY BY THE BUYER ON THE BASIS OF PERIODIC AFTER-THE-FACT EVALUATION OF THE CONTRACTOR'S PERFORMANCE AGAINST SPECIFIED BROAD CRITERIA FOR EACH PERFORMANCE PERIOD
  - FEE CAN BE AWARD ONLY BUT AWARD FEATURE IS NORMALLY INCLUDED WITHIN A FIXED OR INCENTIVE FEE STRUCTURE
  - AWARD FEE DECISION IS UNILATERAL AND NOT SUBJECT TO DISPUTES CLAUSE PROCEDURE

APPLICATION:

- MAY BE USED FOR HARDWARE DEVELOPMENT AND TEST CONTRACTS UNDER NORMALLY CPFF OR CPIF SITUATIONS WHERE AN AWARD FEE PROVISION IS CONSIDERED AN APPROPRIATE MOTIVATION TO MANAGEMENT TOWARD THE ACCOMPLISHMENT OF CONTRACT OBJECTIVES
- ALSO USED FOR BASE, MISSION SUPPORT, AND COMPUTER CENTER OPERATION AND MAINTENANCE CONTRACTS

TIME AND MATERIAL/LABOR HOUR CONTRACTS



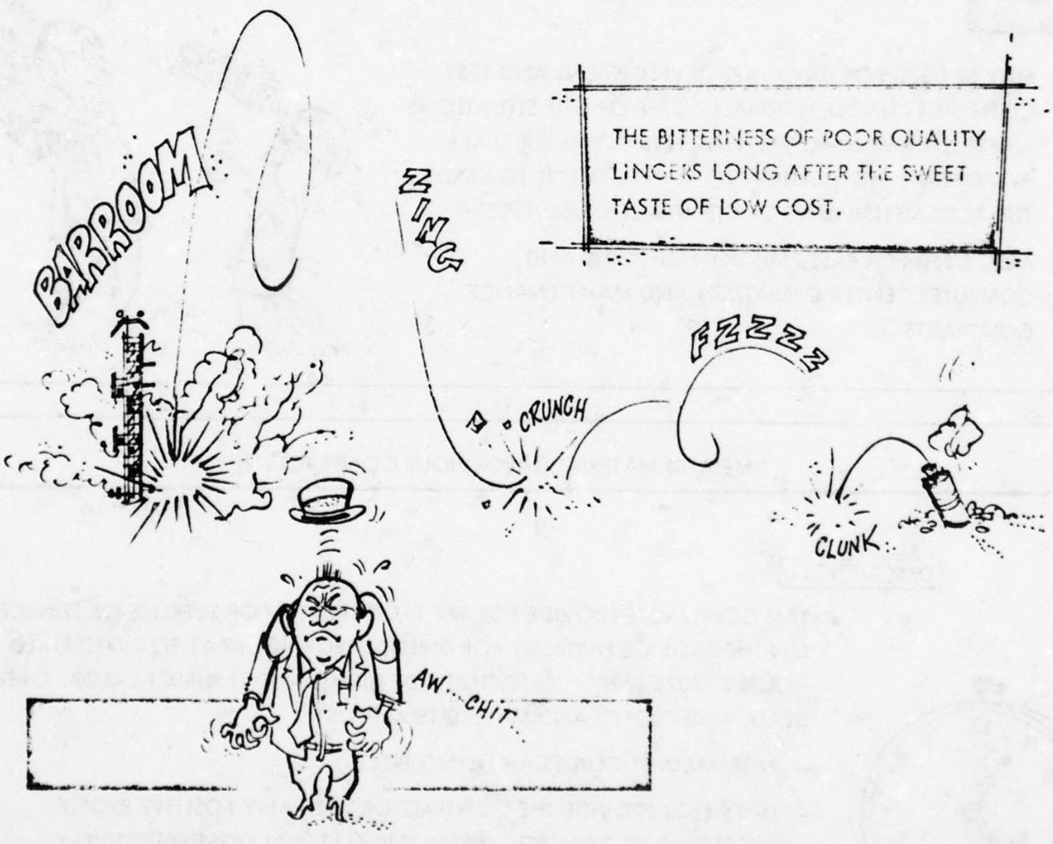
DESCRIPTION:

- T&M CONTRACTS PROVIDE FOR THE PROCUREMENT OF SUPPLIES OR SERVICES ON THE BASIS OF PAYMENT FOR DIRECT LABOR HOURS AT SPECIFIED FIXED HOURLY RATES (WHICH RATES INCLUDE DIRECT AND INDIRECT LABOR, OVERHEAD, AND PROFIT) AND MATERIALS AT COST
  - NORMALLY INCLUDES A CEILING PRICE
  - DOES NOT PROVIDE THE CONTRACTOR WITH ANY POSITIVE PROFIT INCENTIVE TO CONTROL LABOR AND MATERIAL COST EFFECTIVELY
- LH CONTRACTS ARE SIMILAR TO T&M TYPE CONTRACTS AND DIFFER ONLY BECAUSE THE CONTRACTOR IS NOT REQUIRED TO FURNISH ANY MATERIAL

APPLICATION:

- USED ONLY IN THOSE SITUATIONS WHERE IT IS NOT POSSIBLE AT THE TIME OF PLACING THE CONTRACT TO ESTIMATE THE EXTENT OR DURATION OF THE EFFORT OR TO ANTICIPATE COSTS WITH ANY SUBSTANTIAL ACCURACY
  - E.G.: REPAIR, MAINTENANCE, OR OVERHAUL WORK

CROTSER'S CREED



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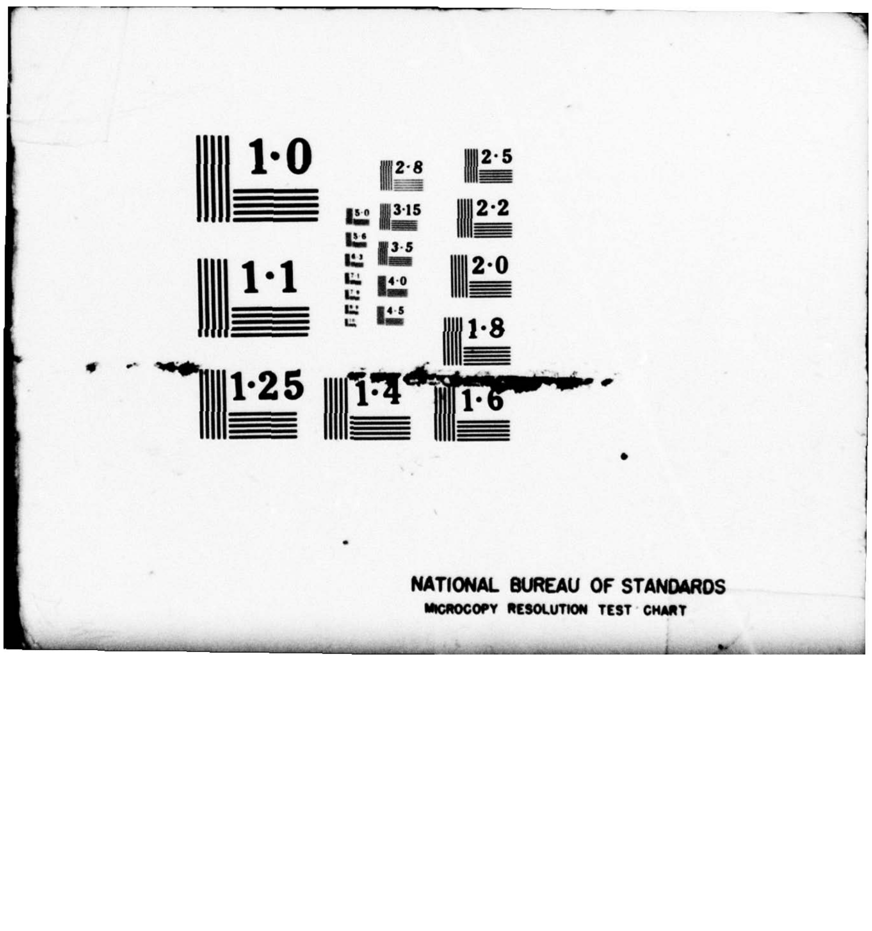
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NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

THE ROLE OF CONTRACTUAL INCENTIVES

Mr. Patrick R. McGinnis
Director of Contracts
McDonnell Douglas Corp.
Huntington Beach, CA

"To be meaningful, contract incentives must motivate the incentivized party to apply more emphasis on key program issues than he would have applied absent incentives." Mr. McGinnis continued this theme by showing if we are to focus attention then the candidate elements (cost, schedule, performance) and the candidate events must be identified and prioritized.

Three primary considerations must be addressed:

(1) The total amount of potential earnings to be tied to incentives and the allocation of that amount across incentive elements and events.

(2) Selected incentive events must be examined to assure they can't inadvertently contribute to program problems (encourage unadvisable technical shortcuts or unrealistic estimates).

(3) Incentive flowdown to individuals.

On this last consideration, Mr. McGinnis shared an experience of McDonnell Douglas with incentive flowdown. In a recent CPAF contract for off-site performance, the company set up an arrangement to share 60% of the award with <u>all</u> the employees. Mr. McGinnis observed that in this situation, each individual could accurately identify his role in attaining the award. This experience invoked a lot of interested discussion from the floor. The audience was skeptical about whether this arrangement would work in other than an off-site contract. There was also some doubt that most corporate management would settle for such a low total profit on a substantial size contract.

On the subject of award fees, Mr. McGinnis favored their increased use if applied within the following guidelines:

(1) "The Government should provide broad guidelines for the Incentive Plan and prioritize them. The contractor should be allowed to propose the details of the plan.

(2) Both parties must understand the total earnings available.

(3) Subcontractor and individual flowdown must be addressed.

(4) The motivational aspects of the <u>award</u> fee vis-a-vis the <u>incentive</u> fee should be compared and evaluated.

<u>The Value of Incentives</u>

- To be meaningful, contract incentives must motivate the incentivized party to apply more emphasis on key program issues than he would have applied absent incentives.

- Assuming the prospect of more (or less) than base earnings serves to focus emphasis, the candidate incentive elements must be prioritized, i.e., cost, schedule, performance; and the candidate incentive events within the schedule and performance elements must be identified.

- Having selected the elements and events to be incentivized, three primary considerations must be addressed:

  1) The total amount of potential earnings to be tied to incentives and the allocation of that amount across incentive elements and events.

  2) Selected incentive events must be examined to assure they can't inadvertently contribute to program problems (encourage unadvisable technical shortcuts or unrealistic estimates).

  3) Incentive flowdown to individuals.

  The latter consideration must be viewed from the standpoint of whether maximum motivation can be attained by increasing the profit potential of the contracting entity or by increasing the earnings of individuals working on the contract by means of a specific flow through of incentive dollars.

- The preceding comments relate to <u>objective</u> incentives (bonus or penalty relates to meeting a specific and predetermined cost, schedule or performance goal). Use of subjective (award fee) incentives have increased in recent years. The motivational aspects of the <u>award</u> fee vis a vis the <u>incentive</u> fee approach should be compared and evaluated.

ARE INCENTIVES EFFECTIVE?

Mr. Harold E. Sharp
SAMSO, Chief of Pricing

Mr. Sharp started his presentation by providing three questions which must be asked whenever one is considering the use of performance incentives, i.e., are the incentives: (1) desirable (2) attainable (3) measurable. Mr. Sharp suggested that when SAMSO and the Air Force look at Mission Assurance, they look at the Total Program. He identified this as a problem from the government's viewpoint since we do not contract for a total program. The launch vehicle, spacecraft, launch services, and orbital support, though all a part of the total program and required for mission success, each is contracted for separately and consequently, the incentive environment is splintered. Mr. Sharp suggests that the incentive plan would be different in a competitive environment than in a sole source environment. He believes that when the two sides to a negotiation have a large difference in total price, the performance incentive becomes a mechanism to give both sides what they want.

Mr. Sharp recommends use of the Predetermined Incentive Plan. In the ideal situation, the buyer and seller would agree on the details of the incentive plan without addressing dollars prior to the start of negotiations.

After these remarks, Mr. Sharp shared the SAMSO incentive experience and statistics with the audience.

THE VALUE OF INCENTIVES AS A MOTIVATION FOR HIGH MISSION ASSURANCE

1. Kinds of Motivation
   a. Company Image
   b. Long range business
   c. Pride of the individual and/or team
   d. Profit (immediate contract)
2. Origin of the Incentive Plan
   a. Competitive Environment - dictated in RFP, with limited input by contractor.
   b. Sole Source Environment
      (1) Negotiation technique to sweeten the "deal" by increased profit potential for lower costs.
      (2) Predetermined incentive plan based on Program Offices desires. Fine tuned during negotiation.
      (3) Follow-on buys - similar to previous contract.
3. Structuring Performance Incentives
   a. Go-no-go
   b. Steps functions
   c. Linear
   d. Non-linear
4. Interdependency
   a. Implicit
   b. Explicit
5. Trade-Off Analysis
   a. Three dimensional trade-offs
      (1) Cost share line and limits (ceiling price, max/min fee)
      (2) Performance par, limits, probability and distribution
      (3) Timing and future value of payment
   b. Graphic techniques
      (1) Isofee curves
      (2) Nomographs
      (3) Incentive cost/profit graphs and overlays
   c. Problems in creating "ideal" trade-offs
      (1) "Ideal" isofee curve
      (2) Combining linear cost and performance incentives
      (3) Non-linear performance incentives
6. SAMSO Incentive Plans
   a. Satellite
   b. Boosters
   c. ICBM
   d. Other

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SAMSO SATELLITE PERFORMANCE INCENTIVES

PROGRAM/CONTRACT DESCRIPTION	TYPE	SHARE/ PERCENT	% INCENTIVES SCHD	% INCENTIVES PERF	MONTHLY DOLLAR INCENTIVES NEGATIVE AMT ($000)	NEGATIVE MOS	POSITIVE AMT ($000)	POSITIVE MOS	PAR YRS	TOTAL YEARS	TIME OF PAYMENT
1. DSCS II 6 Satellites	FPIF	80/20 T.P 11.0% C.P 125%	+1.1	+15/ -10	91.7	12	0 91.7 22.9	12 12 24	1-2	5	Bimonthly after 2nd year
2. DCCS II 4 Satellites	FPIF	80/20 T.P 11% C.P 120%	+1.2	+15/ -10	131.6	12	131.6 65.8	24 24	1	5	Bimonthly after 1st year
3. FLTSATCOM 2 Satellites	FPIF	80/20 T.P 6.1% C.P 125%	+6.4	+13.4	-0-		91.5	36	0	3	Pre-pay after c/o
4. FLTSATCOM 1 Satellite	FPIF	80/20 T.P 12% C.P 120%	-0-	+6.7/ -4.5	75.0	24	75.0	36	2	5	Pre-pay after c/o
5. DCSC III 2 Satellites	FPIF	80/20 T.P 4.1% C.P 124%	-0-	+27/ -9	306.3	12 Overlap	91.9	120	0-1	10	Bimonthly
6. NATO III (2) 1 Satellite	FPIF	60/40 T.P 12% C.P 125%	-3	+8/ -9	61.4	36	81.9	24	3	5	Bimonthly after 3rd year
7. NAVSTAR (2) 3 Satellites	FPIF-AF	80/20 T.P 6.2% C.P 126.2% A.F. 2.5%	-0-	+4.3/ -1.4	11.4	36 Overlap	30.6	36	0-3	3	Annually
8. DMSP 2 Satellites	FPIF	* T.P 11.5% C.P 128%	+1.5/ -0.3	+7.5	-0-		98.6 30.6 40.9 41.2	2.5 8.2 6.1 6.1	1.5Mo	2	Milestone

*95/5 T.C. +8%
90/10 T.C. +(9-13%)
75/25 T.C. +14%
75/25 Underrun

NOTE:

(1) Amounts shown are for basic negotiated contract values
(2) Competitive awards

SAMSO PERFORMANCE INCENTIVES — OTHER (1)

PROGRAM CONTRACT DESCRIPTION	TYPE	SHARE/ PERCENT	INCENTIVES
1. TITAN — TRANSTAGE INJECTOR	CPIF	85/15 Over 90/10 Under T.F. 8.3% Min. 1% Max. 15%	+$267K/-$178K Improved Specific Impulse Performance +6/-4%, Schedule +1.2%
2. TITAN-LAUNCH SERVICES	FPIF	T.P. 11.7% C.P. 118%	No Fail / 1 Fail / 2+ Fail Under 60/40 75/25 100/0 Over 80/20 80/20 80/20
3. TITAN-LAUNCH SERVICES	FPIF	70/30 Over 85/15 Under T.P. 11.4% C.P. 120%	No Fail / 1 Fail / 3+ Fail +$30K* +$20K* -$50K** * Per Successful Vehicle ** 3rd and Subsequent Vehicles
4. MINUTEMAN-MK 12A PRODUCTION	CPIF	85/15 T.F. 7% Min. 4% Max. 10%	Production Hour Incentive ± 1.8%
5. MINUTEMAN-GYRO ACCELEROMETERS (PIGA) FY 76	FPIF	75/25 T.P. 10.8% C.P. 117%	MTBF 1000 Hour: Increments ±14.5% Min 45,000 Hrs, Par 75,000 Hrs. Max 100,000 Hrs
6. MINUTEMAN-GYRO Accelerometers (PIGA) FY 77	FPIF	75/25 T.P. 10.2% C.P. 115.2%	MTBF 1000 Hr, Increments ±12.7% Min 55,000 Hrs, Par 100,000 Hrs. Max 224,000 Hrs

NOTE:
(1) Amounts shown are for basic negotiated contract values.

ARE INCENTIVES USEFUL TO ACHIEVE MISSION SUCCESS?

Mr. Grant L. Hansen
President
System Development Corporation

Mr. Hansen's remarks were of particular interest to the audience in light of his past experience as Vice President for Space of the Convair Division of General Dynamics and as the former Under Secretary of Defense for Research and Development. The complete text of Mr. Hansen's remarks follow and were the stimulus for much discussion during the remainder of the workshop.

Colonel JuVette, fellow panelists, ladies and gentlemen – it's a pleasure for me to be here.

Like baseball, hot dogs, apple pie, and Chevrolet, mission success is all-American goodness and we are all for it. I hope this series of workshops can help us to get more of it. I am honored to be a participant in this panel which is considering the benefit of contractual performance incentives in improving mission success probability through contractor management motivation. It is a worthy subject and I do have some ideas about it, which I am pleased to have this opportunity to express.

I was privileged to have been a participant in one of General Morgan's sessions with industry representatives to discuss what our Air Force-Industry team can do to enhance the chances of achieving the 100% success record we all want. I commend those who have organized these meetings so that we can all expand on what has already been done.

Since I originally agreed to participate in this panel, I have retired from General Dynamics and joined System Development Corporation of Santa Monica. Therefore, I can no longer speak for General Dynamics and I'm too new at SDC to speak for them, so I'll just speak for myself. I do have inputs from both companies and I will review the use of contractual performance incentives at Convair, talk about why launch vehicles are different from spacecraft and take the position that for today's launch vehicles, at least, there are better ways for the Air Force to spend their mission assurance money than by putting it into contractual performance incentives.

In the 1950's and early 1960's we were almost more surprised when a launch vehicle went right than when it went wrong. The first Atlas ICBM launch was June 11, 1957 and it was unsuccessful. During the next two years there were twenty-five Atlas launches and fifteen were unsuccessful. During the next five years there were another hundred Atlas launches with only sixty-five successful ones. The overall reliability to mid 1964 was only 60%. Everyone tried hard, but the machines were very complex and immature. Murphy's law was having its heyday. Everyone was concerned about low space launch reliability and struggling to do something to improve it.

Our first management financial incentive was when John Rubel, who was then in DOD, made a $10 bet with Jim Dempsey, who was then General Manager of Convair, that we couldn't get seven or more successes out of the next ten Atlas space launches. Most of us who were working on the program shared Rubel's belief that he could easily win that bet. Jim Dempsey had a very fancy plaque made, with a space identifying each launch and indicating success or failure. He hung the plaque prominently in his office so that it couldn't be missed by any of us or any visitor who went into his office.

No one can ever prove whether that bet helped, or whether the configuration had simply matured to the point that it was ready to start working better anyway, but Jim Dempsey won that bet going away! Nine of the ten launches were successful.

A special type of success motivation was put into the Atlas program when it was designated as the launch vehicle for the Mercury Astronauts. Those astronauts visited our plant and talked with all of our people, so that they had a personal identification with the mission and understood that everything had to be done just right to preserve the safety of those great American heros.

When John Glenn was launched, I thought he must be the most courageous, or foolhardy, person who had ever lived. I felt that if he knew as well as I did how many things were capable of going wrong he would never have agreed to go. I guess he probably did know, but I just had no idea what a man might go through in order to get elected to the Senate!

The Mercury Program, as we all know, was a 100% success. When it was completed, the Air Force, NASA, Aerospace Corporation, General Dynamics and the Atlas associate contractors conducted a three day workshop so that the industry and all who were interested could hear about all the things which were done to deliver that 100% success record. Contractual performance incentives still had not been used in the Atlas Program, but our confidence in our ability to deliver success was beginning to be quite high. All of the special care features of the Mercury launch vehicle program were incorporated into the Atlas Space Launch Vehicle program on a routine basis.

Another very special kind of success motivation technique was used by NASA and the Congress during the early days of the Centaur Program. The first launch was May 8, 1962. Ten days later, Congressional hearings were started to review that failure and the Centaur program in general. Within a few more days we had a full scale GAO investigation going, which lasted for several months. NASA transferred Centaur responsibility from the Marshall Space Flight Center at Huntsville to the Lewis Research Center in Cleveland and gave us one more chance. Congress had promised to watch the program very carefully.

Our next launch was 27 November 1963 and we all knew that launch had to be a success or our program would be cancelled. Reporter Bill Hines of the Chicago Sun had already prepared an article assuming failure and dubbing Centaur as a "Thanksgiving Turkey". Fortunately, that flight was a big success. The only thing which dampened our jubilation was that the country was in mourning for President Kennedy's death and we were not permitted to have a launch success party.

For the next several launches, we were still hanging on the ropes, very fearful that any launch failure would trigger a new round of Congressional and GAO

investigations, with the end result of program cancellation. We all carried a card which said "HOPE". That acronym stood for "Help Our Program Endure". We were on a CPFF contract, but we just couldn't have been more motivated. After each successful launch we fully appreciated Winston Churchill's words when he said "There is nothing more exhilarating than to be shot at and missed!"

We were especially nervous about our ability to successfully support the Surveyor program for soft landings on the moon. We understood the importance of Surveyor to readiness for the Apollo manned landings and were keenly motivated for success but trembling with the knowledge of how many things could go wrong. The 100% success record on launching of seven Surveyors established our confidence that the Atlas-Centaur launch vehicle combination could be a reliable work horse of the new space age, and it has been.

Of all Centaur launches, 38 out of 41 have been successful. Since the D Model reliability improvements, 20 out of 20 have been successful, with 2 no-trials because of booster failures. Special attention was given to the Titan Centaur and it has had 100% success for 6 operational launches. After the "Preparedness Program" of hardware and procedure changes, the E and F Models of Atlas have had 52 out of 57 launches successful or 91% and the SLV-3 Atlas has had 94 successes out of 99, or 95%. Anything less than 100% is unacceptable – that's why we're here. The person whose mission just failed doesn't care about the 53 straight successes you just completed prior to his failure.

Convair's first performance incentive contract was negotiated with the Air Force in 1962. It was for the development, production and launch of Atlas Standard Space Launch Vehicles. Many reliability improvements were included, in addition to the special care features which had been learned from the Mercury program. The Mercury program had used the basic Model D version of the Atlas ICBM vehicle, with some changes for mission adaptation, safety and reliability. The new Atlas, SLV-3, was to be the best and most reliable vehicle we knew how to build.

To the best of my knowledge, the Atlas SLV-3 contract was the first launch vehicle contract with contractual launch and mission performance incentives. The actual performance formula was somewhat complicated, but essentially it provided plus or minus incentive fee for variations from a stipulated target reliability performance goal. The maximum performance incentive fee was achieved at 90% reliability. We did earn the maximum fee. In my den at home, I have a nicely framed picture of Col. Leo Sullivan, Atlas SPO Director at the time, presenting me with a check for nearly $4 million. We had achieved a reliability of 94.3% for the 35 vehicles under that contract.

Because that vehicle series was redesigned for reliability, because the configuration and manufacturing procedures were maturing, because the crew was gaining experience and confidence and because we had a new contractual performance incentive, it is impossible to separate the variables and independently assess the value of the contractual performance incentive fee. Because it was the first of its kind for Convair and because a lot of flexibility for contractor action existed (most of which has since disappeared), most people would agree that senior management attention was drawn to the program more thoroughly by the incentive fee prospects. This may have resulted in a better reliability record than we would otherwise have had – a point which can't be proven or disproven. Nature has a way of not revealing the results of unused alternatives.

I do know that I really enjoyed receiving the performance fee check, I prize the picture of it being presented to me, and I know that it made our Controller and my bosses very happy.

The follow-on contract for Atlas SLV-3 launch vehicles was negotiated in 1965 and provided fee penalties for anything less than 100% success. The penalty was a pre-established amount for each vehicle failure. There was considerable opposition to this arrangement within General Dynamics – the argument being that negatives were not as effective motivators as positives. It's the old stick versus carrot motivation argument which I don't think anyone has ever won, but a consensus view is that some of each is probably better than either alone.

As a compromise with Convair, the Air Force finally agreed to a special bonus of about 1% fee for 100% success. The penalty for each failure remained.

That contract was completed in 1968, with a reliability record of 100% for twenty-eight vehicles. Convair received the special bonus fee. Since that time, the government has shown no further interest in performance incentives for Atlas SLV-3 space launch vehicle contracts. Also, General Dynamics has not pushed for this feature in follow-on contracts. I'll say more about this later, but I would first like to round out the historical perspective on contract performance incentives at Convair.

In the late '60s and early '70s Convair had two performance incentivized contracts for modification, Aircraft Inspection and launch of E and F Model Atlas ICBM-s which were left over from the deactivation of the Atlas Weapon System. These "wheat fields birds" have been and are being used for space launches from Vandenberg Air Force Base as well as for re-entry vehicle testing and as targets for ABM testing in the South Pacific.

Some definition of terms is relevant to understanding the results of these contracts. A success is defined as the payload completing its flight objectives or the Atlas delivering the payload to the end conditions specified by the Air Force for each flight. A failure is when the payload does not meet its flight objectives and the cause is attributable to Convair equipment or services. A "No-Trial" is defined in four ways:

1. The flight is terminated or the payload mission objectives are not met for reasons outside of Convair's area of direct responsibility, or
2. Determination of responsibility for failure cannot be made, or
3. The government directs a launch against the recommendation of Convair management, or

4. The vehicle was not launched within a prescribed calendar time after production delivery.

The actual results may help explain why the Air Force has shown no further interest in performance incentives for follow-on launch vehicle contracts. Those contracts included thirteen vehicles to be launched within a time period ending ten months after the DD250 on the thirteenth launch vehicle. Only eleven vehicles were launched within that time period and eight of the eleven were no-trials. The contract specified a minimum of nine vehicles to be evaluated, so under the terms of the contract a performance fee of 9/13 of the maximum incentive fee had to be paid.

Convair's only other experience with performance incentives contracting in the space business is with the NASA contracts where award fee is extensively used. There is a target fee, typically about 6 to 7%, and an award fee, typically ± a couple of percent, available for subjective judgment by NASA of contractor performance.

While flight success is an important consideration in award fee determination, there are many others and the direct linkage with flight success is obscure.

Having now covered the historical perspective and all of the contract performance incentive experience for launch vehicles at Convair, I would like to make these eight personal observations:

1. As compared to spacecraft contracts, where there are both degrees of performance and length of performance that can be evaluated, launch vehicle performance is strictly a go-no-go situation. Because of the relatively small quantities that are procured under any contract, it is not feasible to use a percentage of total performance as a goal; hence, as we have seen in our experience, the tendency to move toward fixed bonus/penalty arrangements. This results in the undesirable situation from the Government standpoint that they may have to pay a large bonus to a launch vehicle contractor even though the mission was a failure because of upperstage or spacecraft failure. Though I have no direct evidence, I have a feeling this was one of the reasons why the Air Force dropped the incentives on the SLV program.

2. In Convair's case, and I suspect for most launch vehicle contractors, there is no contractor total systems responsibility; i.e., engines and guidance systems are provided as GFE. Because of this there are situations wherein the launch vehicle contractor is denied a bonus payment he otherwise would have earned because of a failure of GFE. The Government has recognized this aspect of the problem and has in effect tried to pressure launch vehicle contractors to assume responsibility for the GFE systems even though they had no contractual arrangement, nor any real control over the associate contractor. Additionally, this divided responsibility makes it difficult to determine the responsibility for failure.

3. Because of launch schedule slippages, the launches sometimes take place months or even years after the vehicle is manufactured. Since the basic design for most launch vehicles was done years ago, what is really being incentivized is quality and workmanship rather than design reliability. Incentives paid years after the work has been performed are not in my opinion very effective motivators. It may well be that the people who actually did the work are long gone or on a different project by the time the incentives are paid. This is further complicated by the fact that quite often the vehicles are launched on a different contract, and there is in effect a divided responsibility.

4. I understand most spacecraft contractors are in favor of incentives. Having some knowledge of the special incentive type programs used to pay them, I can understand at least one reason why. In the ones with which I am familiar, <u>all</u> fee was ultimately earned as incentive fee, but in fact the contractor normally drew down a healthy advance payment of fee either on a cost reimbursement basis or upon completion of milestones. He then earned fee against that payment if the spacecraft performed, and could earn, assuming 100% success, 15% of the negotiated cost. If spacecraft performance is poor, the contractor may ultimately have to pay back some or all of the previously collected fee. Given the development time for spacecraft, this method even under the worst circumstances assures him the use of Government money for a period of years.

   In Convair's launch vehicle contracts incentive fee has never been a major component of the earned fee. Given the lack of total systems responsibility, they would be reluctant to accept a contract which did not provide a healthy minimum fee. Obviously they could not be in a position of being deprived of earnings because of an associate contractor failure. Under these circumstances, I am not sure that the incentive awards for launch vehicle performance can ever be made large enough to be significant motivators.

5. Having had an opportunity to participate in Convair's operation under both incentive and unincentivized contracts, I am of the opinion that there was essentially no difference in our approach to management or motivation. The real incentive to successful performance on launch vehicle contracts is the avoidance of the pain, turmoil and loss of image that goes automatically with a vehicle failure. Our ultimate goal has always been to sell more launch vehicles, and failures don't help the sales curve.

   Early in the Convair launch vehicle pro-

gram we put success/failure record boards in the program management, engineering, production and launching areas. After each launch a posted addition to the "track record" is made showing the results of that last launch. These launch reliability record boards are watched with great interest by all concerned and I believe they have been a motivating force.

6. The primary motivation is pride. Each individual involved takes pride in success and feels very badly about failure. This is the best possible motivation because it is well understood that when the total mission is successful there is great pride for everyone. If the mission is unsuccessful, there is little consolation in the fact that "I did my job right". This is a great motivator to help others, in addition to doing one's own job right.

7. Having been through many failure analyses and reviews it is a well known fact that after a failure, the people involved work day and night and weekends for weeks diagnosing it all, determining the corrective action, creating the reports and <u>attending all those meetings</u>. Family and other personal obligations must be temporarily set aside – typically for a few weeks. We've tried success and we've tried failure – success is infinitely better! I don't think individuals can have any stronger motivation to help produce success.

8. Launch vehicle configurations and procedures are very mature and the reliability data base is large. The last Atlas launch was number 439. Experience has taught us many ways to improve reliability. Most of these changes have been incorporated into the hardware, the software or the procedures. However, some have not – because of lack of available funds, lack of agreement that the change should be made, or lack of feeling that the number of remaining expendable launches can justify a reliability improvement change.

A recent consensus of Convair senior technical and management people was that if the Air Force has additional money for improvement of launch mission assurance, it should be spent on recommended improvements to the hardware rather than on contractual performance incentive fees. However, I doubt if the financial types or the shareholders would agree. They like that extra profit from incentive fees.

For my own part, my personal opinion is that contractual incentivizing of launch success will not improve the result. The Air Force is already getting a very high level of motivation and dedication from the people in its highly developed and mature launch vehicle programs.

DO MANAGEMENT INCENTIVES REALLY WORK?

Mr. Robert J. Ingersoll
Contracts Mgr. - MX Program
The Boeing Company

During Mr. Ingersoll's presentation, the following points were discussed:

1. Question from the audience: "Is management motivated differently through objective (performance) incentives and subjective (award fee) incentives?"

Mr. Ingersoll: "Only a few know when 100% performance incentive is earned, but everyone knows when 100% Award fee is granted. The Award fee gets much more publicity."

2. Comment from the floor on the use of Award Fees:

   a. Should be evaluated 3-4 times per year.

   b. Evaluation stimulates corrective action.

   c. Evaluation criteria are key; i.e., they must be clear and directed toward desired objectives.

   d. There should be an opportunity for the contractor to defend his award claim.

3. Recommendation from the floor was to somehow merge the Design-To-Cost (DTC) and Value Engineering (VE) concepts in the new Defense Acquisition Regulations.

Do Multiple Incentives Really Work?

I. Why Multiple Incentives?

II. Types of Contractual Incentives

III. Multiple Incentives Will Work, If

   A. Selection of Appropriate Incentives

   B. Structuring of Incentives

   C. Proposing Incentives

   D. Negotiation of Multiple Incentives

   E. Multiple Incentives as a Management Tool

Why Multiple Incentives?

The justification for multiple incentives is to focus management attention on those costs, deliveries, and performance requirements of importance to the Government by incentivizing the contractor where it counts: Profit.

Contractors should accept this challenge knowing that multiple incentives can yield very reasonable profits.

Types of Contractual Incentives

Can be developed within almost any contract arrangement, but usually developed within a CPIF or FPI structure.

Cost Incentives

- Sharing Formulas (Penalty/Reward)
- Targets
- Ceilings
- Floors
- Buffer Zones

Schedule Incentives

- Examples: End item delivery, test completion, final acceptance, etc.
  - Go-No-Go
  - Penalty Only
  - Reward Only

Performance Incentives

- Mission Success-Payload, Speed, Range, etc.
- Independent
- Interdependent

Other Incentives

- Design to Cost
- Warranties
- Value Engineering
- Correction of Deficiencies
- Termination-Default
- Award Fees

Multiple Incentives Will Work If

Selection of Appropriate Incentives

Incentives Interdependent

Motivate contractor to strive for maximum fee in all areas by establishing an attainable range of incentive effectiveness.

If maximum performance cannot be achieved, incentive structure should compel decisions be made consistent with program objectives by assigning relative weights to each incentive area.

Structuring of Incentives

Structuring of multiple incentive arrangement must be done by team effort (Government and contractor where possible).

Selective incentive parameters.

Identify minimum acceptable, target, and maximum desirable level for each parameter.

Assign percentage of importance to parameters.

All incentive outcomes should be acceptable.

Proposing Incentives

Firm definition and understanding of work statement exists.

The solicitation describes the Government's minimum requirements, performance goals, and the type of contract which is contemplated.

Result in an incentive plan with proper emphasis on incentive objectives.

Negotiation of Multiple Incentives

More incentive contract profit dollars can be made by a competent technical-contractual-financial team throughout the incentive plan preparation and negotiation than by all the program management possible after the contract has been negotiated.

The first objective is to negotiate cost incentive.

Negotiate performance incentive.

- Don't forget exemptions to maintain status quo
  - Causes beyond the control of the contractor
  - Acts of God, nature, or public enemy
  - Acts of omissions of other contractors or the Government
  - Government furnished property
  - Abnormal economic fluctuation
- Unique circumstances to consider for effect on incentives
  - Special funding requirements
  - Types of subcontracts
  - Method for effecting 'changes'
  - Method and timing of payment
- Negotiate multiple incentives so that maximum profit is attainable to achieve the utmost incentive goal.
- Use multiple incentives as a <u>contract</u> management tool so that:

  A. System requirements are more clearly identified and defined.

  B. Middle management and field site operations become more aware of program goals in all areas of cost, delivery and performance.

  C. Mathematical models of the incentive plan can be formulated to permit monitoring performance goals, e.g., weight, drag, and thrust, in relation to technical progress, cost and schedule status.

  Incentives create profit goals and therefore are the measurements of management.

Multiple Incentives as a Management Tool

- Before incentives, management would not want to <u>violate</u> the contract but now management wants to <u>fulfill</u> the contract.
- Management from top to bottom must understand:

  The goals or milestones that are incentivized

  The measurement of incentive success or failure

  The profit dollar rewards associated with success and penalties associated with failure.

ORGANIZATIONAL EFFECT OF ADMINISTERING INCENTIVES

Mr. Hubert L. O'Brien
TRW Space Systems Division

Mr. O'Brien began by conceptually constructing an organization. The organization has a purpose; it can define, communicate, and measure goals; and it can reward achievement. He went on to relate this concept by buyers, sellers, and individuals.

Mr. O'Brien gave several examples from his corporate experience of the various types of incentives and of some of the problems encountered. He showed how TRW, in a couple of instances, through the use of multiple incentives, was in a situation where they would have received their greatest monetary reward for poor performance or failure.

He impressed on us the requirement for continued emphasis on reasonable cost estimating. He stated that buyers and sellers perform for a variety of reasons other than profit or cost savings.

A comment on profit or incentive sharing with employees suggested caution in this area. Mr. O'Brien stated that experience shows that this approach motivates the best individuals to gravitate toward the most successful programs leaving the "problem program" in even greater difficulty.

- Develop the concept of <u>any</u> organization or enterprise
  - Organized for a <u>purpose</u>
  - Define goals
  - Communicate goals
  - Measure goals
  - Reward achievement
- Relate the 5 concepts to the
  - Buying activity
    - Government or
    - Industry prime contractor
  - Selling activity
  - People as individuals
- How contract incentives motivate organizations and people (with examples and "war stories")
  - Cost incentives
    - Cost realism
    - Cost sharing
    - Contract type — risk
  - Performance
  - Schedule
  - Award fees
    - Overlap
    - Mission success pools
    - Double whammies

SAMSO ORGANIZATIONAL CONSIDERATIONS
IN INCENTIVE CONTRACTING

Col John J. Caulfield, Jr.
Director of Procurement for
Space Communications Systems, SAMSO

The attached "Mid-Term" Examination was devised by Col Caulfield as a discussion tool. The text of Col Caulfield's remarks are quoted in their entirety.

"Since you folks are approximately half way through this Mission Assurance Conference, I have facetiously organized my outline in the form of a mid-term examination.

Question No. 1

1. The purpose of incentive contracting is to motivate the ________ to performance which is in the best interests of the ________.

- We begin with a "fill-in-the blanks" question.
- I'll give you a hint – the two missing words are Government and Contractor.
- Which word goes where?
- Try inserting Government in the first blank and you get...
- On the other hand, if you insert the word Contractor first, you get...
- Note that grammatically both words work equally well in either position.
- But SAMSO's goal is to motivate the Contractor to performance in the best interests of the Government.
- Why then, does the typical SAMSO RFP contain a detailed incentive plan which is presented to the contractor as a given?
- Perhaps it derives from an organizational arrogance.
- After all, if the word Government fits in either of these blanks, then the Government should be able to play two roles: that is

  (1) The Government should be able to stipulate what is in the best interests of the Government

  and

  (2) What will motivate the contractor to achieve it.

- Maybe we ought to instead invite the bidding contractors to propose incentive plans that they find meaningful.

Question No. 2

2. What is "...in the best interests of the Government"?

   A. Technical Performance
   B. Cost
   C. Schedule
   D. Socio-Economic Achievement
   E. All of the above
   F. Some of the above

- By the way, what is "...in the best interests of the Government?"
- TECHNICAL PERFORMANCE is the traditional answer – the school solution.
- But more and more COST has become a major determinant of program success.
- And in the satellite business, we are expecting launch costs to skyrocket come FY81 and the Space Shuttle.
- Incidentally, the Government has an array of less obvious, more subtle, interests which it pursues through our systems contracts.
  - Hire the handicapped
  - Equal economic opportunity
  - Small businesses
  - Minority enterprises
- Confidentially, look for future SAMSO RFPs to provide an award for achievement of minority enterprise subcontract goals.
- I guess what I'm saying is that the pressure is on our organization to pursue a variety of Government interests.

Question No. 3

3. How do you measure technical performance?

   A. Meets or exceeds all specifications.
   B. Meets or exceeds some specifications.
   C. Achieves design life in orbit.
   D. Achieves mean mission duration.
   E. Stores unobtrusively in orbit.
   F. Stacks nicely in warehouse.

- Question No. 3 also causes lots of organizational soul-searching.
- We paid the contractor to meet all specs., *why should we now accept anything else?*
- But all or nothing somehow doesn't seem fair, so why don't we pay him for meeting the spec. for critical modes...or for being on the air most of the time, if not all the time?

- By the way, how long should the incentive period run?
- The spec. may prescribe a design life of 5 years, but the Failure Modes and Effects Analysis (FMEA) will likely calculate a so-called MEAN MISSION DURATION of 36 or 40 months.
- Organizationally, how do we make the critics of defense procurement understand that we are not giving away the farm when we agree to pay an orbital incentive at the end of 3 years, when the design life is 5 years?
- Sometimes we are faced with storing a satellite in space, in orbit, in order to have it immediately available if and when needed in the future.
- How do we handle that in terms of incentives?
- Organizationally, we find it difficult to justify paying an incentive for something we aren't using.

Question No. 4

4. How do you reconcile sometimes conflicting technical requirements of the various *payloads of multi-mission spacecraft?*

   A. Carefully

   B. Other (specify)________.

Question No. 5

5. True or false:

   A. Incentives are budgeted for the fiscal periods in which they are expected to be earned.

   B. Advance payment of incentives is contrary to public law.

   C. Milestone billing provisions for liquidating progress payments can be a form of incentive.

   D. The design-to-cost concept poses unique incentive problems.

   E. The cost plus award fee type contract enables the Government to change its mind on its incentive priorities over the life of a contract.

   F. A contractor gets discouraged when the Government is unable to place his satellites in orbit.

   G. "Non Multa Sed Multum".

a. Incentives are budgeted for the fiscal periods in which they are expected to be earned. Poses practical problems...Given a Federal Budget System that only extends 5 years into the future. How do you budget for incentives for a system with a 10-year useful life?

b. Advance payment of incentives is contrary to public law.

c. Milestone billing provisions for liquidating progress payments can be a form of incentive.

d. The Design-To-Cost concept poses unique incentive problems. How do you incentivize a production DTC Boogy years in advance of signing a production contract.

e. The Cost Plus Award Fee type contract enables the Government to change its mind on its incentive priorities over the life of a contract.

f. A contractor gets discouraged when the Government is unable to place his satellites in orbit.

g. "Non Multa sed multum."

   It is quality rather than quantity that matters.

   - Lucius Annaeus Seneca, 8BC – 65AD.

ORGANIZATIONAL EFFECT OF ADMINISTERING INCENTIVES

Mr. George S. Pappas
Director of Contracts
Ball Aerospace Systems Division

Mr. Pappas began his remarks by stating that his company's experience is as a medium-sized contractor with only a minor fraction of their business in Government Aerospace contracts.

He suggested that to evaluate the results of contractual incentives, one must ascertain what was done differently because of the incentives. Any review of this nature will get a distorted picture because of the other variable factors present. That is to say, that it is nearly impossible to isolate two situations which are identical except for the incentives and to identify the effects thereof.

In Mr. Pappas' experience, he sees no trade-off analyses being made of incentive factors. This elicited several instances of contrary experience from others in the audience.

Mr. Pappas stated that profit sacrifices are made in the process of acquiring and performing a contract, but there are practical limits to these sacrifices. From his perspective, the contractor will occasionally take a low profit rate if the contract will allow the corporation to broaden their technical expertise. This, he asserts, is one of the motivations for Government business.

Mr. Pappas feels that extra-contractual considerations such as: expansion of operations; reputation building; and coverage of corporate G&A expenses; dominate over profit and fee.

Mr. Pappas made the following points about incentives:

1. There is no significant correlation between cost sharing ratios and overruns/underruns.

2. Incentives are very costly to administer.

3. Contractors will not sacrifice performance for profit.

4. Incentives do not work to the disadvantage of the Government.

5. Incentives serve as a planning discipline for DOD personnel.

6. Incentives clearly communicate Government objectives to the Contractor.

In his closing remarks, Mr. Pappas states that "The Government never gets what it contracts for in CPFF contracting. It does get what it wants because contracts are ill-defined early on."

INCENTIVE INNOVATIONS

Lt Col Michael M. McMillan
HQ AFSC

Lt Col McMillan began his presentation by discussing current trends within the AFSC acquisition environment. Most of the items covered are of special interest to the new AFSC Commander, General Slay.

Some observations made by Lt Col McMillan:

1. The Government does not do a good job of preparing and sharing "Lessons Learned" in the systems acquisition process.

2. As presently used, the Business Strategy Panel is..."an exchange of ignorance" because one of the major entities concerned is missing; the contractor.

3. The key to a successful program is: Early Identification of Program Objectives.

4. There are no innovations. We must learn to apply what we have more effectively.

5. The use of the Draft RFP is the contractor's opportunity to share opinions/approaches with the customer.

6. We must all (buyer/seller) do a better job of trade-off analysis.

7. The Government must do a much better job of identifying all contractor motivations.

The AFSC Acquisition Environment

A-109 Implementation

Firm-up cost, schedule, performance baselines — changes require formal direction/funding

Renewed emphasis on QA in program offices

Past Performance — Major area in source selection

Shift to FFP contracts for follow-on production

Shorten/simplify procurement leadtime

CS^2 3rd level of WBS

What Really Motivates Contractors?

Profit?

Cash flow?

Pride in products (S)?

Public opinion?

Increased share of the market?

"INCENTIVE CONTRACTING IN SPACE"

Mr. P. Nino Noal
Director of Contracts
Defense Systems Division
Hughes Aircraft Co.

Mr. Noal observed that the eleventh speaker in our all-day workshop runs the risk of repeating much of what has been said. Mr. Noal's presentation served as a valuable summary and underscored several important points.

Some comments of particular interest to the audience were:

1. Good corporate publicity is a major motivator for contractors.

2. A concept worth pursuing is the total application of an Award Fee to Orbital Performance.

3. A lot of floor discussion was generated when Mr. Noal suggested that some circumstances may warrant use of the "Umbrella" concept for major subcontractors. In this situation, all major subcontractors are incentivized in equal proportion to the prime.

4. Mr. Noal briefly mentioned the use of the "Martin Incentive" discussed earlier by Mr. Crotser. He confirmed that this has been shown to be effective when properly administered.

5. Since space missions now normally last from three to seven years, how do we shift incentive award criteria to match mission objectives which change during this period?

6. Probably the best incentive structure is one which incorporates a proper mix of multiple incentives and an award fee.

<u>Incentive Contracting in Space</u>

- Contractor must have stake in mission success
- Incentive must be heavily slanted on performance
- Continuing emphasis on innovative ideas important
- Susceptible to stereotyping

<u>All Award Fee on Orbital Performance</u>

- Leaves most tradeoffs to contractor
- Must have "structure" in award fee plan at start of program
- Contractor must "feel" program objectives
- Requires thoughtfulness and program integrity

<u>"Umbrella" Concept for Major Subcontracts</u>

- Where subcontractor effort is critical to success
- Creates closer identification with mission success
- Forces continuing cooperation

<u>"Making Out A Check"</u>

- Does it get management attention?
- Can it cause ruin through inattention?

<u>Matching Changing Mission Objectives</u>

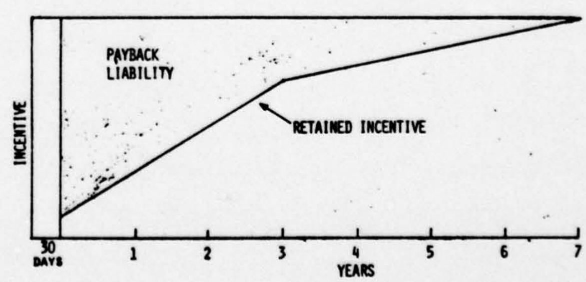
- Incentive criteria fixed 3-7 years prior to mission performance period
- Mission objectives can change or shift emphasis
- Incentives can become "fee-measures" only
- Award fee or other ideas to treat the problem

<u>Multiple Incentives Plus Award Fee</u>

- Not really new — one early example was NASA's Surveyor program
- Allows continuing government influence throughout the program — changing emphasis as appropriate
- Difficult to structure — tradeoffs are agonizing — complex to administer — but probably the best

COMMERCIAL CONCEPTS APPLIED TO MILITARY PROGRAMS

- **TENDS TO SHIFT MISSION ASSURANCE RESPONSIBILITY TO CONTRACTOR**
- **EXAMPLE:**



WORKSHOP SUMMARY

WORKSHOP SUMMARY

Summary Remarks

The following observations and recommendations were made as a result of the Contract Incentive Workshop:

- All parties involved in creating and administering multiple incentives must be cautious not to create a counter-productive incentive structure. We must insure that tradeoff analyses do not result in motivation which tend to degrade the mission. Action: SAMSO/Industry

- To determine whether contractual incentives truly motivate a contractor, many factors must be evaluated. It can be said, however, that they will be ineffective if they are too complex and not fully understood by both parties. A straw vote within the workshop on the question, "Do Contract Incentives Motivate?" resulted in a nearly equal split between yes, no, maybe. Action: SAMSO; must insure simple, easily understood incentive arrangements.

- There was virtually unanimous agreement on the desirability and usefulness of the Award Fee. It was felt that the use of periodic awards provides real time feedback to the contractor on his performance. It also allows the flexibility to adjust award criteria with changing government requirements and emphasis over the long life of present day space programs. Contractors report that top management attention is easily focused by the Award Fee "report card". It was also noted that in the proper circumstances, even bench level workers can share the award and be effectively motivated. Recommendation: SAMSO and Industry continue to use in a judicious manner.

- Another recurring theme heard throughout the day was that there are many, frequently more effective, incentives to contractors than the promise of increased profit. Pride and publicity were mentioned most frequently as top management attention-getters. It was noted that a successful space mission filters throughout the corporate structure. The government could get a lot of mileage out of a well handled mission publicity program that publicly recognizes the contractor's contribution. It was also stated by several attendees that personal and corporate pride will always prevent a contractor from making profit enhancing/mission degrading decisions. Other extra-contractual incentives mentioned are: positive cash flow (milestone billings); corporate growth; increased market share; follow-on business; utilization of available skills and plant capacity; and absorption of fixed costs.

- Increased mission duration of today's space programs have resulted in incentive payments over an extended period. Current interest rates and inflation tend to discount the value of the downstream incentive payments. It was felt that the customer must study alternatives which address the time value of money when constructing long term incentive plans. Action: SAMSO/PM.

- A recommended improvement to incentive plan preparation was discussed. This approach would be to have the customer provide broad guidelines and priorities to be incorporated within the plan. With this information incorporated in the RFP, the contractor would then propose a detailed incentive plan. The obvious advantage of this approach is that the contractor is the one who can best determine what his major motivators are and the negotiation process should distill the optimum structure for the particular situation. Action: Individual Buying Agency. P.S. SAMSO/PME, in response to this recommendation, has recently released an RFP with this approach.

- The Space Shuttle era will require new incentive approaches. Recoverable payloads; on-orbit testing; reentry survivability are but a few of the anticipated issues which will undoubtedly affect the present risk environment of space programs. Recommendation: Government and Industry must jointly explore the Shuttle environment and recommend alternative incentive approaches.

WORKSHOP C

THE ROLE OF PROGRAM REVIEWS, INDEPENDENT REVIEWS AND AUDITS IN MISSION ASSURANCE

Co-Chairmen

Col. James A. Smith, SAMSO
Special Assistant to Vice Commander

Mr. Sheldon C. Shallon
Chief Scientist
Defense Systems Division
Hughes Aircraft Company

Workshop Coordinators

Mr. Edward Newman, SAMSO/AW
Mr. Dan Browne, SAMSO/AW

AGENDA

Wednesday, April 26

0830-0845	Workshop Overview	Col. James A. Smith, SAMSO
0845-0910	The SAMSO Program Management Review Process	Lt. Col. Gordon L. Carpenter, SAMSO
0910-0930	Industry Corporate Visibility for Mission Success	Mr. Mark Sasso, RCA
0930-0950	Progressive Acceptance Reviews and Audits	Mr. Frank J. Wolf, Hughes
0950-1010	Break	
1010-1030	Role of Continuous Internal Audits	Mr. Heinie Shaw, TRW
1030-1050	Internal Review — A Management Control	Mr. Walter L. Finch, Lockheed, LMSC
1050-1130	Contractor's Approach to Independence in Program Reviews	Mr. Ben J. Wier, General Dynamics
1130-1300	Lunch	
1300-1700	Summary of Workshop Objectives and Open Discussion	
1700	Adjourn	

THE ROLE OF MANAGEMENT AND THE PROGRAM REVIEW PROCESS IN MISSION ASSURANCE

Col. James A. Smith, SAMSO
Special Assistant to Vice Commander

Objectives:

1. Exchange views within industry on corporate program review policies, techniques, and practices which appear to enhance mission assurance.

2. Assess if present industry/government review process is optimum for mission assurance - recommended changes.

Discussion Areas:

1. Involvement of senior staff and line management to what degree of program detail.

2. Timing of senior management involvement (periodic, key milestones, crisis oriented).

3. Industry review teams' contribution to mission assurance, timing, and need for independence.

4. Involvement of prime management in review process of subcontractors.

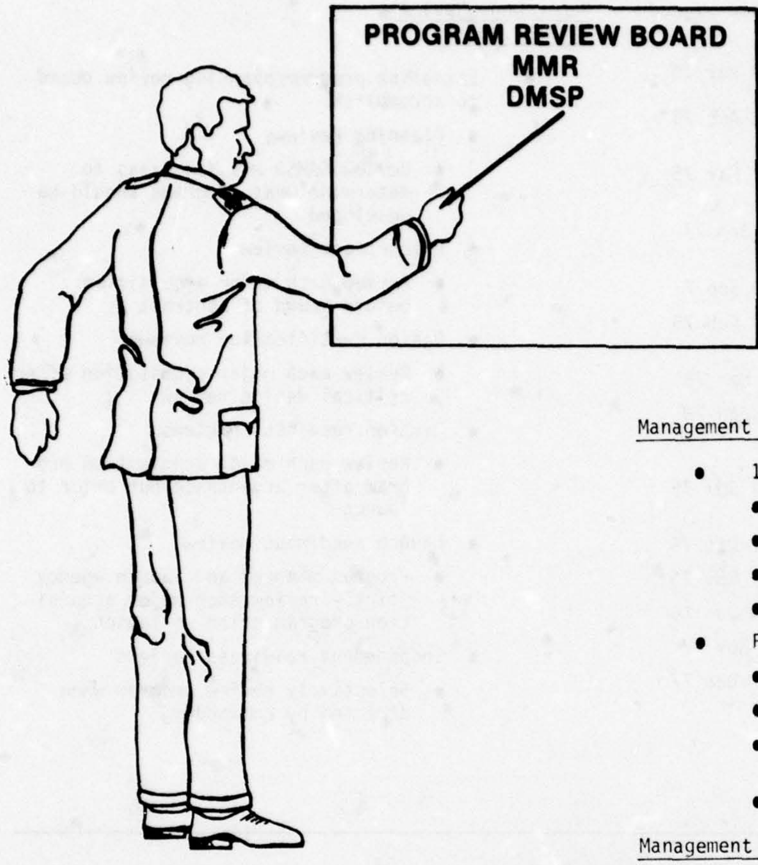
5. Need and role for special reviews and audits.

6. Usefulness and timing of government review process in mission assurance.

7. Roles and mix of industry/government review teams - keep separate or join forces.

SAMSO Independent Readiness Reviews

- Initiated because of failures
- A last check on programs which are
  - New
  - Significantly changed
  - Unusually complex
  - Identified with previous failures
- Formal process with direct channel to Vice Commander
- Significant findings by recent teams



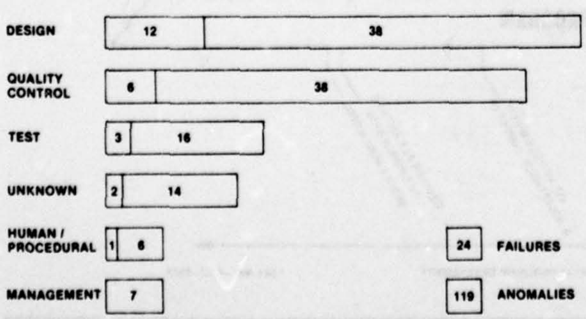
SAMSO MANAGEMENT REVIEW PROCESS

Lt. Col. Gordon L. Carpenter,
SAMSO, Chief, Problem Analysis Center

Background

- Number of failures/anomalies occurred in 1971
- SAMSO Commander established a failure review committee
- Committee chaired by Vice Commander
- Objectives committee
  - Evaluate all failures/anomalies for minimum of 5 years
  - Review current development programs
  - Development working groups
  - Make recommendations

FLIGHT FAILURES / ANOMALIES BY CATEGORY



Management Actions

- 1972 failure review determined
  - Lack of management involvement
  - Poor quality programs
  - Design and test deficiencies
  - Poor quality parts used
- Four working groups organized
  - Management working group
  - Quality working group
  - Design/test and human procedural working group
  - Piece parts working group

Management Working Group

- Problems found
  - Lack of incorporation of lessons learned from other programs.
  - Need for more management involvement throughout life of program.
  - Infuse corporate experience into each program.
- Recommended
  - Development of commanders policy statements - SAMSOR 5-4
  - Development of a corporate review process - SAMSOR 800-3
  - Reorganize directorate of acquisition support.

Status of Commander's Policies
SAMSOR 5-4

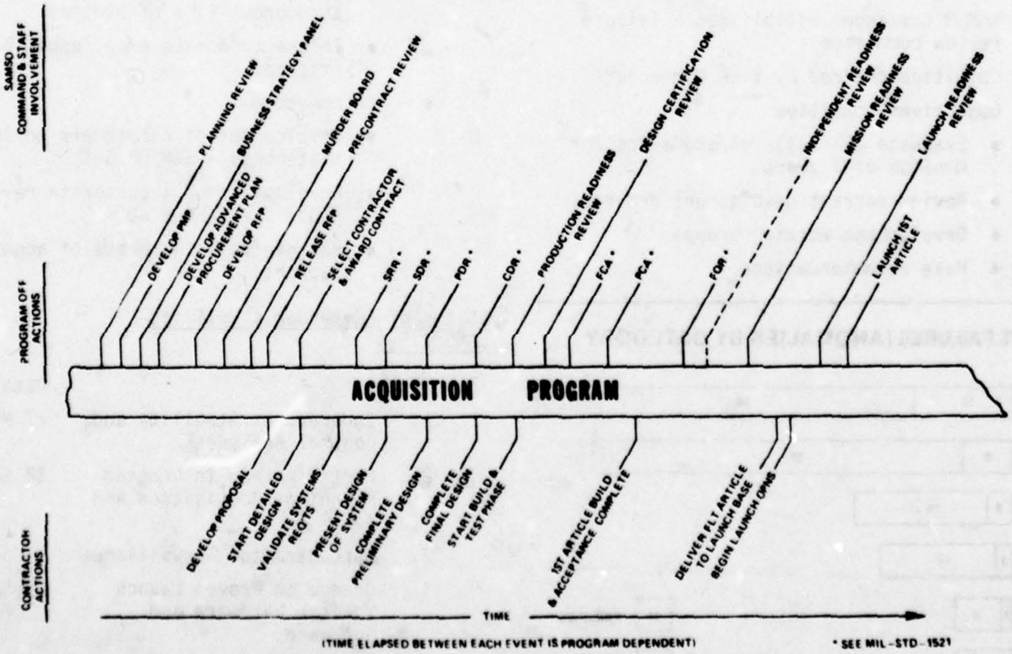
		Date Signed
1.	Independent Stability and Control Analyses	27 Mar 75
2.	Participation in Program Planning, Acquisition and Test	18 Sep 72
3.	Subcontractor Surveillance	17 Oct 75
4.	Change to Proven Launch Vehicle Hardware and Software	29 Sep 75
5.	Control of Launch Vehicle Inventory	29 Sep 75

		Date Signed
6.	Quality Assurance	27 Mar 75
7.	Microelectronics for Space and Missile Systems	18 Aug 75
8.	Independent Structural Load Analysis	27 Mar 75
9.	Management of Computer Resources	5 Jan 77
10.	Accident Risk Management	19 Sep 77
11.	Management Review System for Small Contracts	28 Feb 75
12.	Space Vehicle Testing	3 Mar 75
13.	Independent Readiness Review	4 Jan 78
14.	Independent Stress and Fracture Analysis	24 Jul 75
15.	Production/Manufacturing	17 Oct 75
16.	Pre-Award Surveys	17 Nov 75
17.	Business Strategy Panels	24 Jun 76
18.	System Reviews and Audits	2 Nov 77
19.	Failure Modes and Effects Analysis	27 Dec 77

Management Review
(SAMSOR 800-3)

- Establish program/planning review board to accomplish:
  - Planning reviews
    - Review SAMSO mission areas to determine what programs should be developed
  - Precontract reviews
    - Review each major acquisition before award of contract
  - Design certification reviews
    - Review each major acquisition after critical design review
  - Mission readiness reviews
    - Review each major acquisition program after acceptance but prior to launch
  - Launch readiness reviews
    - Program manager and launch agency jointly review each major acquisition program prior to launch
  - Indpeendent readiness reviews
    - Selectively review program when directed by commander

REVIEW SEQUENCE ON A TYPICAL ACQUISITION PROGRAM



Quality Working Group

Problems Found

- Weak quality assurance programs
- Not enough definitive QA contract requirements
- Lack of quality surveillance by government and contractors

Recommended

- Augmentation of MIL-Q-9858 with space hardware special provisions
- Involve CAO/QA personnel in design and engineering test
- Upgrade quality of DCAS/AFCMD/PO quality assurance personnel
- Establish program office quality assurance manager
- Strengthen subcontractor management

Design/Test and Human Procedural Working Group

Problem Found

- Design not fully checked
- Testing Requirements not consistent
- Procedures not checked and followed

Recommended

- More detailed emphasis on PDR and CDR
- Establish a common space vehicle testing std (MIL-STD-1540)
- Strengthen review of procedures both in plant and at launch site

Piece Parts Working Group

- Problems found
  - Contractors not selecting good quality parts in design phase
  - Contractors not managing selection of parts
  - Quality parts not available
- Recommended
  - Make quality parts available for use by contractor
  - Insure management of parts selection accomplished by contractor
  - Develop special design and test requirements for space parts
  - Develop a SAMSO qualified parts selection list

Implementation

- All recommendations made by working groups were approved
- In 1975, SAMSO Vice Commander, directed that independent readiness reviews be conducted
  - On programs as appropriate
  - About same time as mission readiness review

Summary

Management Reviews

- Improve mission success potential
- Provide management help if needed
- Insure better organization interfaces
- Provide visibility on lessons learned
- Insure AF objectives satisfied

MANAGEMENT RESPONSIBILITIES AND PARTICIPATION

Mr. Mark Sasso,
Manager,
Satellite Programs RCA, Astro Electronics

The objective of this discussion is to identify appropriate management involvement in the program review process in order to provide timely utilization of corporate resources in guaranteeing mission assurance.

The appropriate timing of program reviews will be identified during the life cycle of a program to provide management emphasis during critical design, manufacture, and test phases.

I will also discuss the involvement of functional management disciplines in the review process to assure application of appropriate expertise in the identification and solution of all problem areas.

In order to provide a perspective for this discussion allow me to say a few words about the RCA Government Systems Division and how we are currently organized.

Astro-electronics which is part of the Government Systems Division has just celebrated its 20th year in space. Shortly after Sputnik ushered in the space age, RCA drew upon its broad spectrum of scientific and technological skills and resources to establish the Astro-Electronic Products Division in March 1958. In doing so, RCA became the first in the electronics industry to commit itself to a major role in the new space frontier. Astro-Electronics was charged with the responsibility "to develop and produce earth satellites, space vehicles, and their associated ground equipment."

Actually, RCA's experience in satellite and space research dates back to the early 1950's when it performed various feasibility studies for the U.S. Government. These studies dealt with subjects such as earth-space exploration, meteorology, navigation, and early warning systems.

During its 20 years of space leadership, RCA Astro-Electronics contracted to design and build 116 spacecraft, plus having the responsibility for the development of 38 major systems.

Over this same span, RCA has successfully orbited 72 satellites and has provided 330,640 manhours of post launch on-orbit operational support. The RCA-built satellites have accumulated 102 years of orbital operational life.

In addition to the four product units of which Astro-Electronics is one, there are five main staff functions which provide special resources which can be drawn upon as required by the product units. I will show later the significance of this in the review process.

I particularly want to mention the staff engineering function which in addition to the advanced technology lab contains specialists in microtechnology, parts, materials, and reliability engineering.

Astro-Electronics is organized as a matrix of functional and product operations. Each project is organized under a product business unit. Projects are essentially line organizations with all the necessary technical skills to satisfy the program requirement. They are supported, however, by the functional operations in technical areas requiring highly specialized skills such as structure analysis, materials, parts usage, and product assurance.

At RCA all programs receive extensive management attention at all levels. The philosophy is to conduct ongoing reviews in the primary interest of avoiding problems, not relaying exclusively on the program manager to advise of problems after they occur.

Hence, during the life cycle of a program, monthly reviews are conducted by the program manager for the group Vice President and his staff (one level above the division Vice President). Of primary concern to him are technical problems causing or about to cause program impact and to assure appropriate technical resources are being applied. He is also interested in subcontractor problems and whether appropriate levels of management are involved in problem solutions. Subcontractor effort is also reviewed in much the same manner as our own. During PDR and CDR staff reliability engineering and special technical support is provided to augment our own technical staff. In addition we retain a consulting staff in special areas of expertise to gain added assurance of technical integrity. He is also concerned about current or potential customer concerns and whether there is an appropriate corporate response. When problems arise that cause serious impact in meeting system objectives he will command appropriate application of resources and status reviews will become more frequent.

The Division General Manager also conducts detail reviews with his staff. He is also interested in the programs ability to meet all mission requirements, but he will command all necessary divisional resources to assure timely and proper technical solutions. He will also solicit corporate resources when the situation demands. His staff will make timely audits of all functional processes, engineering, manufacturing and product assurance to avoid problems.

At the operational level the business unit manager conducts weekly reivews of program status. To provide a fine grained analysis of program health and to prevent small problems from becoming major disasters. This provides a continuing look at detail which is absolutely essential in order to guarantee program and mission success.

The program manager never sleeps. His is a daily surveillance of detail program functions. No detail is too small, and on his shoulders falls the ultimate responsibility for providing the visibility of and response to program needs. His is a lonely job, but he has all the clout necessary to bring appropriate management attention to bear in providing system operational readiness.

In addition to the regularly scheduled reviews, we have an ongoing quality and safety audit program conducted by our product assurance function. These are scheduled at irregular intervals and provide assurance that appropriate processes and standards are adhered to in the fabrication and test of the

product. Here again special technical support is provided by the staff functions.

The timing and frequency of the reviews as I have just described would appear to be extremely burdensome from a program management point of view. Indeed very often it seems as though an excessive amount of effort is spent in preparing and providing review data. Program management however, as we all know, is a constant surveillance process and while we may not always succeed, we do manage to choose the timing for the reviews so as to minimize duplicate effort.

I must say a few words on the use of and the value of independency in industrial reviews. First, the control function established through quality control and safety reviews are tools for independent reviews for our management. Also, other staff functions are organizationally established for independent reviews, such as the engineering staff reporting to the general management. They participate and attend design reviews and are available to perform independent analysis of designs and spacecraft anomalies for both the program office and line management. Another independent reviewer is the customer who's program office personnel and his supporting technical and operational support advisors review the program in considerable detail. A separate but formal independent review team, formed by the customer, normally covers the same ground twice but like any reviews makes contribution. For complex and costly space system now being produced, all reviews contribute to the success of a program. The problem for industrial management is to support the review while minimizing the impact on cost/schedules and mission needs.

We at RCA welcome the design reviews. The mission readiness and launch readiness reviews are also productive. Our concern is with improper timing where resources are strained at the expense of hardware readiness. Our recommendations are to plan each review early and to cover it in initial contract negotiation so that adequate preparation can be made.

May I say in closing that industry's role in mission assurance is to be the customer conscience to assure design and hardware integrity. To assure through application of design and control procedures, design reviews and audit programs that mission requirements are met.

To maintain data systems that provide history of test and material discrepancies and demonstrate proper closeout action. To assure the conduct of detailed test data analysis that provides proof of performance compliance. To provide continuing trend analysis leading to appropriate action in the elimination of incipient failures. To maintain effective change control systems guaranteeing control of system configuration.

Finally to present to the customer a system totally defined as to its health and configuration by a scrupulous review process leading to his confidence in meeting mission objectives.

Thank you.

PROGRESSIVE ACCEPTANCE

Frank J. Wolf
Program Manager
Hughes Aircraft Company

Flight Hardware Cycle

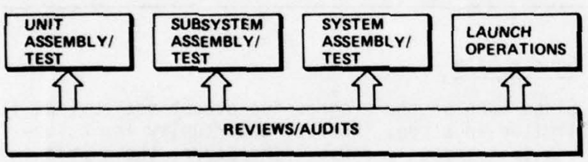
A simplified flight hardware flow diagram is shown which progresses from unit assembly and test, through subsystem assembly and test, to system assembly and test, and eventually to launch operations and, hopefully, results in mission success.

This 2 to 3 year activity is supported or, as some skeptics would say, crutched by a series of planned and unplanned reviews or audits.

Not atypical of Parkinson's law, the number and type of planned reviws are functions increasing with time. Old reviews, like old soldiers, never go away, but new reviews are added contractually. And this assures failure-free orbital operations.

Right?

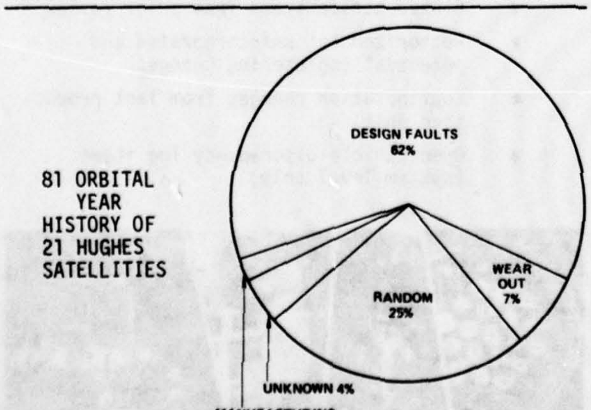
Wrong!



Typical Orbital History

A 2 year old study based on 21 Hughes satellites whose comulative orbital life exceeded 81 orbital years showed that 64 percent of orbital failures could have been prevented, e.g., those associated with design and manufacturing problems.

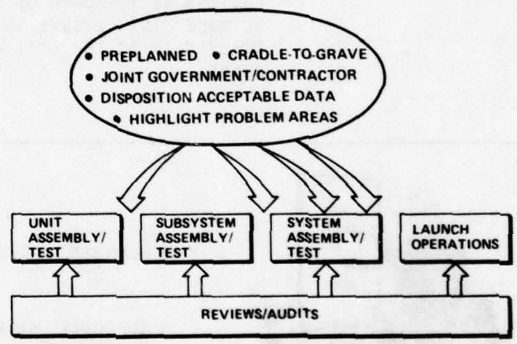
Because of redundancy, conservation designs, and conscious overdesign, success in terms of either incentive earnings or fulfillment of the required missions was well over 90 percent. Nevertheless, a large fraction of on-orbit failures escaped the scrutiny of reviews, audits and tests. This is prima facie evidence that we need more reviews and more tests. Let me suggest that, instead, we need more effective reviews and more effective tests.



Let me now address our concept of progressive acceptance as one technique for more effective reviews. Also, I want to point out that one area of testing has generally been overlooked. At the risk of being guilty of recommending another set of reviews, let me suggest it as a means of increasing test effectiveness.

Progressive Acceptance

What is progressive acceptance? It is really nothing more than a series of adequately planned and properly executed joint Government-Contractor review boards operating throughout the program lifetime, forcing decisions at each meeting and sifting significant data so that acceptable data is reviewed in a timely fashion but not carried forward, and so that liens or postponed actions are highlighted and carried forward to the next review gate.



Effective Reviews

The general thesis is that effecitve reviews are timely, well scoped, and staffed with good people. The specific thesis is how we have applied these principles to the progressive acceptance concept. In the broader sense, maybe you can apply these precepts to other types of reviews or audits inherent in a space vehicle's life cycle.

Timeliness

All progressive acceptance reviews are preplanned and scheduled well in advance to occur at the following times:

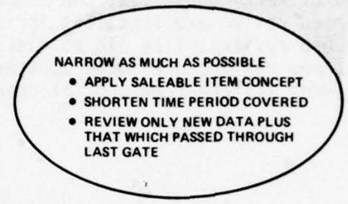
- Unit/subsystem - Approximately 2 to 3 weeks after completion of unit/subsystem flight acceptance test.
- System level - The first system level review occurs about 2 to 3 weeks before system level thermal-vacuum testing.
  - The second system level review is held about 2 to 3 weeks prior to shipment to the launch site or prior to spacecraft storage.
  - Each of these system level reviews is followed by one or more mini-reviews to track data to the critical event.

- **PLANNED**
- **SCHEDULED WELL IN ADVANCE**
- **CLOSE TO EVENT**

Scope

The scope of each review is narrowed as much as possible. Within reasonable limits, a few more reviews, each with limited scope, are more effective than one review covering the entire production cycle. Thus, progressive acceptance reviews are limited in scope as follows:

- Unit/subsystem - Descoped to that box or subsystem which represents a saleable item(s) from the functional area to the system area. Since the saleable item concept is applied, the review covers the single item or group of items tested by the functional area prior to delivery to the system area.
- System level - Descoped to that series of events and tests which have occurred since the last review, plus those items intentionally carried forward from the last review.



Source Data

Since each of the progressive acceptance reviews is limited in scope, there is opportunity for covering that scope in depth. Therefore, the a priori provided source data is extensive. It is also feasible to extend the source data should the board so decide. On a first article production item, it would be normal to spot check or sample some aspects of PDR, CDR, or the qualification hardware. On other occasions, it is in order to spot check closed trouble and failure reports for adequacy of corrective actions.

- Test data, including deviations or waivers
- Open trouble and failure reports
- All prior trouble and failure reports closed "cause unknown"
- Open action items from previous acceptance reviews
- Closed action items from prior review
- Authorized but unincorporated and potential engineering changes
- Configuration changes from last production unit
- Open vehicle discrepancy log items (system level only)

Personnel

This most critical element can be analyzed in four subtopics:

1. Get the best people you can, but limit the number to 5 or 7.

2. In striving for the best people available, consider using some independent board members to obtain objectivity and cross-fertilization.

   Exclusive user of independent members, however, is cumbersome and time-consuming. It is desirable that independent members be available for future reviews to assure continuity and minimize indoctrination.

3. It is also advantageous to have continuous SPO and Aerospace involvement. The Customer does not like surprises, and his continuous sharing of Contractor problems has a net positive effect. Don't let the "dirty linen" syndrome sway you to exclude the SPO at each step of the progressive acceptance path.

4. Being prepared for the review is another key ingredient for achieving effectiveness. The board chairman must insist upon mandatory review of the data package before the formal review. If a pre-meeting session is in order, the chairman should call it. And most important is insistence upon written action items or questions prior to the meeting.

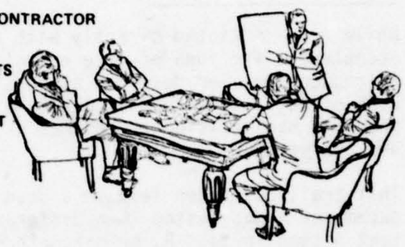
- **THE BEST**
- **INDEPENDENCE IS NOT PANACEA**
- **CUSTOMER INVOLVEMENT**
- **ADEQUATE PREPARATION**

Board Composition

The chairmanship and composition of the boards are based on the buyer-seller principle. Typically, these are:

- Unit/Subsystem Acceptance
  - Chaired by Chief Program System Engineer
  - Data presented by each responsible engineering activity
  - Review Board consisting of technical experts from Contractor, SPO, and SPO technical consultants related to technical subject under consideration.
- Consent-to-Thermal-Vacuum Test
  - Chaired by Vehicle Manager
  - Data presented by Chief Program System Engineer
  - Review Board consisting of technical experts from Contractor, SPO, and SPO technical consultants
- Consent-to-Ship
  - Co-chaired by Contractor Program Manager and SPO Program Manager
  - Data presented by Vehicle Manager
  - Review Board consisting of senior technical experts from Contractor, SPO, and SPO technical consultants

- **BUYER-SELLER PRINCIPLE**
- **JOINT CUSTOMER-CONTRACTOR**
- **TECHNICAL EXPERTS**
- **SOME INDEPENDENT EXPERTS, IF APPROPRIATE**



Documentation

While documentation is time-consuming and expensive, it nevertheless is mandatory.

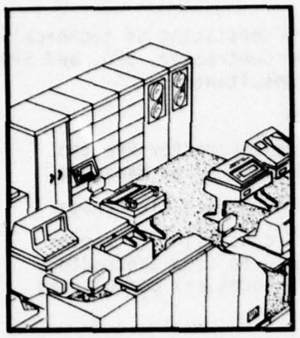
A data package prepared from the source documents is required so that board members can adequately prepare themselves. Written minutes are needed to document the rationale for decisions reached. Written action item assignment and written action item closure are necessary for clarity.

Careful attention to preparation of these documents is invaluable for future reference and precludes duplication of effort.

- Data package
- Minutes of meetings
- Written action item assignment
- Written action item closure

Applicability of Progressive Acceptance

The concept of progressive acceptance is applicable over a wide range of organizational relationships or types of end items. At Hughes, we have used progressive acceptance to incrementally accept major subcontracted subsystems. Even in a first-tier subcontract, we find it desirable to have SPO participation. Progressive acceptance is used routinely for in-house hardware builds. More radical may be the concept of treating data processing end items like space hardware end items. We have tailored and successfully implemented progressive acceptance reviews for major data processing developments. The concept is applicable to any saleable end item.



ORGANIZATIONAL

- PRIME/SUBCONTRACTOR
- PRIME/IN-HOUSE

END ITEMS

- SPACE VEHICLES
- DATA PROCESSING
- ANY SALEABLE END ITEM

Test Plan Review Board

While not associated directly with progressive acceptance, the idea of more effective testing introduced earlier deserves at least one chart. Each of us in this room at one time or another has probably had occasion to conduct or assist in failure analyses.

That trail has often lead to a dead end because parameter N was tested in a different manner in test A than in test B, or parameters N and M, both required to meet requirement R, were tested under different conditions in two different test configurations.

As a result, Hughes has instituted a practice we are continuing to augment, which from an overview level examines how each testable parameter, every time it is measured throughout the production cycle, is tested, and its data recorded and analyzed to assure that parameter traceability is applicable. This permits in-spec trend analysis - a more powerful and sensitive tool than the traditional go/no-go criterion.

GOAL

- IN-SPEC TREND ANALYSIS
- TRACEABILITY

TECHNIQUE

- ASSURE TESTABLE PARAMETER TRACEABILITY FROM ONE TEST PHASE TO EVERY OTHER TEST PHASE

PLAN

- CONDUCT SYSTEM LEVEL INFORMAL REVIEW OF EACH TEST PARAMETER EVERY TIME THAT PARAMETER IS TESTED TO ASSURE TEST MEASUREMENT UNIFORMITY, TEST DATA COLLECTION CONSISTENCY, AND DATA ANALYSIS COMPATIBILITY

Summary

In summary, we need more effective reviews rather than more types of reviews: we need more effective testable parameter traceability.

In my opinion, Hughes management level participation is adequate as constituted in the progressive acceptance concept: the level of participation increases as you progress toward final selloff at the expense of continuity.

Again in my opinion, continuous and joint industry/Government participation is desirable and favored over totally independent review teams even though participation by independent members has some benefits.

I urge each of you to consider adopting a concept like progressive acceptance.

- MORE EFFECTIVE REVIEWS – NOT MORE TYPES OF REVIEWS
- MORE EFFECTIVE FUNCTIONAL TEST PARAMETER TRACEABILITY
- CONTRACTOR MANAGEMENT LEVEL PARTICIPATION
  - ESCALATE LEVEL AS YOU PROGRESS TOWARD LAUNCH/SELLOFF
  - KEEP INFORMED EVEN IF NOT PARTICIPATING
- INDUSTRY/GOVERNMENT MIX
  - CONTINUOUS
  - ESCALATE LEVEL AS TIME PROGRESSES PARALLELING CONTRACTOR MANAGEMENT ESCALATION
- INDEPENDENT REVIEW TEAMS
  - TOTALLY INDEPENDENT – NOT COST EFFECTIVE
  - SOME INDEPENDENT BOARD MEMBERS BENEFICIAL IF SKILLED AND ACTIVE

THE ROLE OF CONTINUOUS INTERNAL AUDITS
IN MISSION ASSURANCE

Mr. W.H. Shaw
Assurance Audit Manager, TRW

The workshop is considering various levels of discrete management reviews. This discussion summarizes a number of contractual and internal management review functions which have been found to work well at TRW. However, undergirding the effectiveness of the discrete reviews are two continuous review processes. The inherent responsibility of each manager for the performance of his people, and the performance of audits to surface faults for manager attention and action. Audits are blended into a comprehensive program at TRW, shaped by Group-level policy. Direction of audit functions (e.g., financial, engineering, assurance, etc.) is assigned to responsible vice-presidents. This discussion reviews the development of the Assurance Audit Program in the context of Mission Assurance enhancement.

In a company under contract for a number of major projects, there is opportunity for transfer of experience. On the other hand, one must guard against inconsistency. This tendency arises from diversity of experience of people, both customer and contractor. Inconsistency causes problems in transferring people between projects, in handling of common facilities and systems, and in communication with central management, with central skill centers, and with customers. Nonstandard systems should be resisted during the proposal and contract negotiation process. Internal management reviews should produce lessons-learned data, and the best experience should be codified in policy, with management insistence thereafter that such standards be followed, or uniformly modified under control as experience continues. System reviews or audits are a means for both enhancing cross-feed of the best operating ideas among projects (which otherwise tend to be insular), and enforcing the management resolve to operate with uniformity. Uniform operating systems need not stifle creativity, but rather should provide a stable routine to allow accomplishing the ordinary tasks with least effort and error while affording a resiliant base for coping intelligently with the extraordinary. Uniform systems and procedures also provide a standard against which reviews (audits, evaluations) may be efficiently conducted.

The TRW Assurance Audit Program is under the direction of a senior manager reporting to the Vice-President and Director of Product Assurance. Its scope includes all the assurance disciplines: QA, Configuration Management, Reliability, and System Safety. The Assurance Audit Office (AAO) is staffed by senior specialists who examine operating systems for adequacy and existence of defining policy. Compliance audits are conducted in functional areas by Quality engineers under the general supervision of the AAO but assigned to the staffs of the Division PA managers. Special audits are also conducted at project request to investigate specific problems or concerns. These have been applied extensively in software projects.

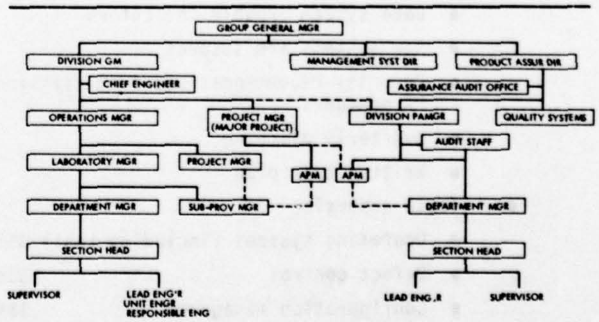
The discussion describes the audit program planning process and the techniques for conduct of audits. Topical emphasis has been:

Operating Systems (Including Test)	35%
Defect Control	35%
Configuration Management	18%
Documentation Systems	12%

Examples of the topics covered and scope are given and short case histories are reviewed to illustrate the effectiveness of the program. The goal of the program is to cause managers to make their operating systems work better. The indirect objective, in the context of this Workshop, then, is more effective project reviews as a result of fewer record discrepancies and lesser volume of paper describing the occurrence and correction of hardware mistakes.

The Role of Continuous Internal Audits in Mission Assurance

- Value of reviews is the preparation they force
- Undergirded by continuous processes
  - Manager responsibility for performance of his people
  - Audit to expose faults for manager action
- Audit Goal:
  - Cause managers to make systems work better
- Indirect objective:
  - More effective project reviews
    - Fewer record discrepancies
    - Fewer hardware faults and related paper
    - Concentration on technical content



TRW Audit Program

- Group level policy
- Functions assigned to responsible V.P.S.
  - Examples: Financial
    Management Systems
    Materiel
    Engineering
- Assurance audits under director - product assurance

Assurance Audit Program

- Senior Manager reporting to VP/Director PA
- System Audits - Existance, Adequacy
  - Senior Specialists
  - All Assurance Disciplines
  - Includes cost considerations
- Functional area audits - compliance
  - Quality Engineers assigned to division PA manager staffs
- Special audits
  - Specific problem investigation
  - Project request
  - Extensive use in software

System Audit Features

- Topical Subjects

  Examples: Materials Review System
  Project CM Plan Implementation
  Test Procedure Validity
- Compares procedure consistency among projects
- Compares performance among divisions
- Involves all levels of management
- Depends heavily upon interviews
  - Work force waiting to be heard
  - Important to protect sources
- Expose problems, not people
- Reports restricted - "Need to know"
- Aggressive follow-up

Audit Conduct and Results

- Topic Selection
  - Data system trouble indicators
  - New systems are suspect
  - Priority recommendations from division PA managers
  - Quarterly planning
  - Written task plan
- Topic emphasis
  - Operating systems (including test) 35%
  - Defect control 35%
  - Configuration management 18%
  - Documentation systems 12%
- Results and observations
  - Insufficient training in new systems
  - Capable work force crutches system gaps
  - First level management defensive
  - Cross-fertilization
  - Advisory source for new system design and discrete reviews

TRW Internal Reviews

Project-Oriented

Monthly management meeting - major projects
Project manager review - monthly
Project staff - weekly
Test program review - test plan
Launch readiness review - weekly
Software division - timeshare data

TRW Internal Reviews

Institutional

Test discrepancy reports - weekly
In-process corrective action boards - weekly
Corrective action boards - monthly
Manufacturer evaluation control board - standing
Configuration management organization - standing
Software policies
Audit program

Review Lessons Learded

- Timing important
  - Too early - insufficient data
  - Too late - opportunity for action lost
- Management level
  - Decision oriented
  - Level necessary to act
  - Overkill produces ineffective review
- Emphasis if resources limited
  - Front load - requirements definition system engineering
  - Software studies - 60% code faults requirements and design
- Preparation essential
  - Necessary data
  - Homework
  - Discussion of alternative
  - Principals understand subject
- Objectives
  - Force communication
  - Focus attention on vaguely acknowledge problems
  - Enforce milestones

Government Review Process

- Issues re institutional reviews
  - Leader has pressures/problems
  - Lead to sweeping conclusions from insufficient data

- Solutions
  - Team Preparation
    - Issues
    - Objectives
    - Approach
    - Assignments
    - Ground rules
  - Contractor interface team - help plan
  - Couple senior contractor people
    - Review manager's staff
    - Morning team sessions
    - Screen results with review manager

Multi-Project Environment

- Opportunity - transfer of experience
- Risk - inconsistency
  - Wastes effort
  - Problems - people transfer
    - common facilities
    - communication
  - Resist during proposal and negotiation
- Management reviews - contribute to solutions
  - Lessons learned
  - Codify best experience
  - Insist upon conformance
- System audits
  - Discover needless inconsistencies
  - Pinpoint areas of confusion or cost
  - Identify policy gaps
  - Cross fertilize

Review Team Mix

- Risks
  - May hide problems
- Benefits
  - Avoid false starts
  - Prevent intemperate or trivial conclusions
  - Prevent contractor resources allocated to wrong problems
  - Get fixes rolling earlier on real problems
- Near-term objectives must be sufficiently common

INTERNAL REVIEW - A MANAGEMENT CONTROL

Walter L. Finch,
Lockheed Missiles & Space Company, Inc.

We all know that a successful mission does not necessarily demonstrate an adequate management control system, let alone one which is optimum. However, continued success reasonably leads one to believe that the management controls are good. Unfortunately we tend to ignore the first and to over-believe the second.

In the event of flight failure there is an immediate reaction - perhaps over reaction! Find the guilty party/equipment and take action to assure that one won't ever happen again! This includes an instant conclusion that something is wrong with the program controls to allow the failure to occur. Any area which could have created failure (or allowed it) is magnified - perhaps out of proportion - and corrective action taken to assure prevention in the future. This could lead one to conclude that our current Government/Industry review process is likely excessive - even to the point it has become counter-productive. As an example, extra controls (that are complex and time consuming) to provide protection against exercise of poor judgment (like failure to follow instructions) when the likelihood of a repeat is unlikely and the added complexity does not prevent bad judgment, only adds cost. Please don't jump to the conclusion I am suggesting flight failure analysis and corrective action are not necessary and proper - only that the resulting actions are often not cost-effective.

The analysis produced long before flight, as a result of prior data, clearly shows the probability of success is less than one. The problem is that a 100 percent reliability is what is really wanted, no matter what is contracted for, and in the real world comes to be what is expected - probably all the way to the Pentagon. The point being that this generates emotional conditions which generate emotional decisions. And in the main it has been like heresy (perhaps a more familiar term would be non-responsive) to suggest anything like elimination of any formal Government requirements/controls. This applies specifically to standards imposed contractually which are supposed to be used as guides and therefore tailored to program needs by judgment. This application of judgment varies widely from program to program - much beyond that one could expect as a result of differences in program complexity, funding, importance, state-of-the-art, etc. It seems to be quite dependent on the ability of the Government Program Manager. He must understand and support implementation of real needs and fend off the "standards zealots" who believe that all contractors are wild men and the specifications/standards must be enforced to the Nth degree to safeguard the Government's interests. Good business practice dictates well defined contractual agreements but good judgment in contractual application of standards is cost-effective and can have a dramatic effect in taming that "wild man".

Let's take a look at our current Space Systems Division management controls to see if they will shed any light on the question of an optimum for Government/Industry. And I would like to alert you right now that with the time allowed there is no way to give a detailed description - so a brief overview followed by in-depth review of some key elements will be my modus operandi.

Our system of controls is probably typical of other major prime contractors and is the result of many years of experience. It includes the advice and consel of many capable and dedicated Government personnel - both military and civilian. Review/audit is accomplished by the General Manager, Program Manager, System Engineering, Reliability Engineering, Product Assurance, Design Engineering, Functional Management of all supporting organizations, and by the Customer. Customer actions are implemented by members of the Air Force Program Office, Air Force Plant Representative, Aerospace Corporation, and by other experts hired by the Customer for that purpose. For our discussion I will group all of these under one category - Customer. The list is long and yet does not include the many working level activities which constitute an independent audit.

The Program Review is handled by the Program Manager and highlights status - problem areas - and open action item assignments. Attendance by Customer varies - in some programs they do not attend but get a special briefing on the results plus notification of any major problem areas. Usually there will be some members of General Management in attendance. The Quarterly General Manager Review covers the same type data but includes all his staff which gets across Program information interchange and opportunity for assistance in problem solution. The same holds true for the weekly Chief Engineer's meeting where technical problems and significant accomplishments are discussed. The Vide President and Assistant General Manager of the Division attends and participates in these meetings. The Top Ten is self-explanatory and is issued by the Program Manager to all levels of management appropriate - including the General Manager. Contract Program Reviews usually are at milestones like System Requirements Review, Preliminary Design Review, and Final Design Review with the format defined by the contract. Parts control is a fundamental requirement for mission success - the subject of another workshop. Let me just mention here that configuration analysis is a System Design Review at the part level - including a FMEA, and a determination of the criticality of the controls of the materials, processes, and assembly techniques used, plus evaluation of the inherent design reliability and effective screening techniques to identify and eliminate parts manufactured with incipient failure modes.

Design review is another fundamental action needed to assure mission success - and the day-to-day activity which preceeds the formal review meeting is a key element - particularly if we are to avoid an undue dependence on the review meeting to accomplish the design - rather than an effort to verify the adequacy of what has been done and, hopefully, to provide some fine tuning. Customer participation varies widely - as does the opinion in regard to effectiveness of this participation. It certainly helps to generate confidence; but it can inhibit the participants. The ability of the individual representing the Customer to create an atmosphere where serious disagreements are likely to be aired is probably the key. The review should be hardware oriented and not an educational process for senior levels of management, and selection

of the Review Team (including assignment of the chairman) is a critical element which should have the active involvement of the Program Manager. The reason for saying so much about Design Review in this workshop - when there is another one on design which will surely cover it in more detail - is that I believe when it is done right the need for special audits later is significantly reduced and will improve their effectiveness when conducted. Get the best people available! Leader key element!

The CCB (Configuration Control Board) is an adjunct to the design review process and needs no additional comment. The system safety activity is an area I don't intend to cover in any detail today. Suffice to say it has been improving steadily and had made significant gains in the past five years. However, the cost of accidents has also increased significantly so that continued emphasis is needed to drive down the accident rate. And efforts are under way to do so. One of the most effective measures to aid this is to avoid panic work hour schedules whenever possible.

The Corrective Action Review Board includes all appropriate functional management, including the General Manager, and is convened whenever necessary to obtain action. This applies to the Senior MRB, too - but they both meet on a quarterly basis to be kep up-to-date in regard to problem status.

The next two items will be covered in another workshop and I will not have any detailed comments. The Qualification Test and Acceptance Test are two more key elements in mission assurance. It is important they be properly defined, the data be objectively assessed, and that we pay attention to the results of the data analysis. The Component Acceptance Data Package Review, therefore, is also a key element. The goal of this should be to identify, through examination of the documentation, any anomaly which could adversely affect the flight worthiness of the unit being reviewed. Since each unit is judged by the team on the basis of the results of the review, there should be no absolute acceptance or rejection requirements. However, if the team's decision is to reject the unit, each unacceptable finding is clearly documented. In addition, specific direction (or a date for that direction) is developed by the team to establish the minimum acceptable rework, repair, or retest.

Let's continue with First and Nth Article inspection and/or audit. This, of course, is related to programs where there is more than one unit planned to be manufactured - but it can also be a useful technique for single unit builds - at least it is worth consideration. It is another key element in mission assurance.

If money were no object it would be preferable to schedule two of these audits. The first would establish a baseline by verifying that the first production unit conforms to the released engineering drawings, and that adequate controls, procedures, specifications, etc., exist to assure that subsequent production would continue to have the same configuration. The Nth would then be picked in some random manner to verify the configuration. However, money is an object as resources are limited. Therefore, where there can only be one it is best done on the First Flight Article.

Regardless of which unit is selected, maximum visibility of the hardware is the major consideration for when the audit is scheduled. The primary interest of the team is examination of the hardware. It is not to be a "dog and pony show" or even a "presentation".

Another facet of the hardware audit is the potential for finding better ways of building the unit. Obviously, the direct approach is when a team member has assisted in the resolution of similar problems at other locations. Indirectly, and possibly of even greater value, is when the team acts as a catalyst to promote dialogue between design and shop personnel. The presence of a "third party" can stimulate the flow of ideas which may highlight long-standing production hang-ups. The shop personnel often have a "better idea", and the climate of the hardware audit can encourage its implementation.

Although the examination starts with the hardware, and much attention is given to workmanship and evidence of quality assurance inspection, questions relating to procedures and processes arise very rapidly. Since the goal is to achieve repeatable reliability, it isn't enough to find the hardware in excellent condition -- that may only reflect the skill of an operator who may retire or be laid off before the next unit is built.

As an illustration of this, let me relate an incident observed at one of our suppliers. We were witnessing a critical welding process and the operator was handing us the small pieces for examination as he completed them. To a person familiar with welding, these parts were a thing of beauty -- penetration was perfection, splatter was non-existent. They couldn't have been better if they had been hand-picked for display purposes. One member of the team, familiar with the set-up and controls for such machinery, asked the operator how he knew what settings to use. (There were about four separate controls to adjust on this machine depending on the job to be performed.) The operator indicated that a procedure was available and one was brought in very quickly. However, none of the variable controls were set in accordance with the procedure. When asked what would happen if the settings were made per the procedure, the operator replied, "Here, I'll show you." He changed the settings and welded several parts which had been scrapped for other reasons. The results were astonishing! The welding literally blew some of the delicate parts into fragments and in no way was the end result acceptable. This skilled operator had been compensating for the aging of the machine for several years. Another operator, unfamiliar with the process, wouldn't have a ghost of a chance to build good hardware using the existing procedure.

I can almost hear some of you saying right now, "That's not such a big deal!. It would easily be caught by Inspection." That's probably true for the illustration; but might not be with a different operator who also made his own settings which resulted in hardware with an incipient failure mode. Think a little! I suspect each of you could identify some operation in your plant where the deviation from the procedure would produce a subtle, but possibly critical anomaly that might not be easily detected. That is one thing the Nth Article Audit seeks to identify and eliminate.

Another example is related to manufacture of a multilayer PCB. A mask for a contact had slipped after wash and etch resulting in a trace width being inadvertently narrowed - but with enough width to be possible to pass acceptance tests and represent an incipient failure mode in extended flight use.

This brings me to the last item on this chart. The hardware audits are intended to be performed down to the nitty-gritty. A flight failure due to a minor problem is no different than one from a major anomaly. Looking at it another way -- it is proper that the only findings of an audit are minor ones. After all, at the time a hardware audit is conducted, the best efforts of skilled personnel have been applied to the design and fabrication of the hardware for a year or more. In addition, there have been numerous hours of technical interchange with the Responsible Equipment Engineer as well as a couple of Design Reviews. It would be a blow to all our prides if something major had been overlooked.

I have already indicated personnel selection to be a key element in Design Review. This chart shows the organizations represented on the teams involved with the last three types of reviews discussed. For an adequate review, it is necessary to balance product familiarity with objectivity/independence. This appears to be accomplished and at the same time there is consistency of composition.

The running sell is the final key element in our system to provide mission assurance. The chart is self-explanatory and the data is used at DD-250 and the Launch Readiness Reviews. As a matter of fact, having done those tasks well as described earlier, the DD-250 and Launch Readiness Review activities should be relatively simple and routine.

I would like now to provide you my summary of the significant conclusions one might reach based on experience weighted by the data presented. This includes some consensus of working level and management personnel, of both functional and program organizations.

Reviews or audits as an in-line function generally are more effective than special audits. There are several reasons for this and they mostly relate to the key elements for any successful audit. They are:

1. Proper timing so that (a) results are meaningful, (b) work load of auditees is not so heavy as to create an additional hazard from interruptions by the auditors.

2. Sufficient effort to make careful selection of audit team.

3. Support of Senior Management to assure objectivity/independence of audit -- and action on findings where necessary.

4. Good definition of scope and objectives of the audit - plus any special ground rules.

5. Pre-planning to define method/manner of conduct of audit.

6. Clear team member assignments.

7. Chairman must be in charge.

8. Must be free of State findings -- whatever they are -- with basis. Results should go first to manager responsible with time to evaluate/discuss/refute/take action/decide on action, etc., prior to any inputs at higher level within some pre-established time limits.

9. Make sure the audit team has no built-in requirement to find problems in order to justify their selection on the team or to demonstrate the omnipotence of the 'auditors'.

10. Audit team needs to have product knowledge and independence.

11. Recognition by team and auditees that review needs to be in "nit-picking" detail - that some of the findings will likely appear minor in nature - and that is not bad since one would not expect to find major problems after the very best people had "done their thing".

12. Remember that state-of-the-art has been carefully reviewed/analyzed/audited, etc., by almost everyone any way connected and usually by the most capable personnel from both technical and management disciplines - while non-state-of-the-art generally gets perfunctory review/manpower/time/funding, etc., and more often than not is the item which really gets you in trouble.

It should be apparent from this list that it is much more difficult to satisfy the needs for a "special" audit. The timing is usually wrong: with work load too high; insufficient time for anything but a surface check; best team member selections not available; little or no time available for action unless a fault were identified which clearly spelled out doom for the mission - and these are not very likely.

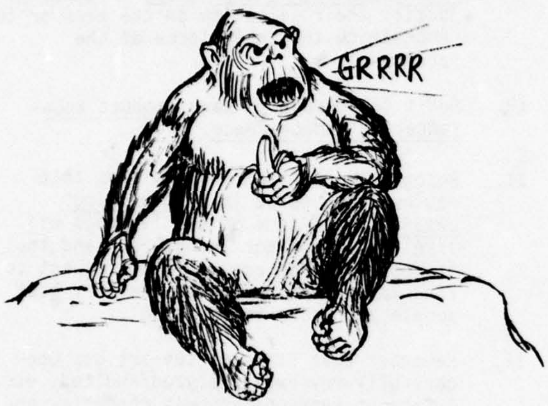
It also appears that the system in being has sufficient controls - independence - and management attention to provide for mission assurance. Tiger teams and special audits over-done get looked on as a panacea and I believe motivate people subconsciously to do less thorough work than they would otherwise. In addition, they seem to encourage every agency to get into the act so that busy people don't have time to do their jobs - with the possibility that this overkill is a counterproductive action. On a running basis it would appear that adequate independence is provided through the Chief Systems Engineer and Reliability Engineering functions. For special audits, however, one should go outside the program/function being audited (either within LMSC or A or AF) for chairman and at least some of the team members.

On the spot Customer Program Office Representatives appears to be an effective method of operation if they are provided authority to make decisions and are truly knowledgeable in the discipline. Otherwise, they are just another layer of reviewers who provide data for top side decisions. Any outside

talent used should be selected on the basis of the experience/expertise they add; with a caution to make sure their experience is really relevant to our products and they become familiar with the equipment prior to participation in reviews/audits.

The system now in being, with some minor tuning and attention to detail, will provide that optimum system for mission assurance.

THINGS AREN'T ALWAYS WHAT THEY SEEM



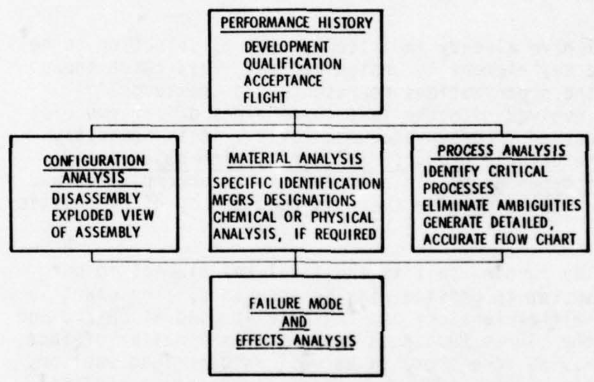
SSD REVIEW/AUDIT LIST

QUALIFICATION TEST (PRIOR TO FINAL DESIGN REVIEW)	SCHEDULE
SOURCE INSPECTION	AS REQUIRED
ACCEPTANCE TEST	SCHEDULE
COMPONENT ACCEPT. DATA PKG. REVIEW	SCHEDULE
COMPLIANCE VERIFICATION MATRIX (*TECHNICAL PERFORMANCE MEASUREMENTS*)	CONTINUOUS
INTERFACE CONTROL WORKING GROUP MEETINGS	SCHEDULE
MANUFACTURING PROGRAM REVIEWS	WEEKLY
I ST AND N TH ARTICLE INSPECTIONS/AUDITS	SCHEDULE
SPACE VEHICLE CUSTOMER BUY-OFF RUNNING SELL	SCHEDULE
DD 250	SCHEDULE
READINESS REVIEW	SCHEDULE
SPECIAL AUDITS	SCHEDULE

SSD REVIEW/AUDIT LIST

PROGRAM REVIEW	WEEKLY
GENERAL MANAGER REVIEW	QUARTERLY
TOP TEN PROBLEM REPORT	WEEKLY
CONTRACT PROGRAM REVIEW	MAJOR MILESTONES
CHIEF ENGINEERS MEETING (V.P. & ASST. GEN. MGR. ATTENDS)	WEEKLY
PARTS CONTROL BOARD (AS REQUIRED)	MONTHLY
GIDEP ALERT SYSTEM	REGULAR
CONFIGURATION ANALYSIS	SCHEDULE
PREFERRED PARTS LIST/PROGRAM CONTROLLED PARTS LIST	START
DESTRUCTIVE PHYSICAL ANALYSIS	SCHEDULE
DESIGN REVIEW	SCHEDULE
CONFIGURATION CONTROL BOARD	AS REQUIRED
SAFETY REVIEW BOARD	MAJOR MILESTONE
PROGRAM SYSTEM SAFETY COMMITTEE	WEEKLY/MONTHLY
CORRECTIVE ACTION REVIEW BOARD	AS REQUIRED
SENIOR MATERIAL REVIEW BOARD	QUARTERLY
AFQA STATUS REVIEWS	MONTHLY
QUALITY SYSTEMS AUDIT	CONTINUOUS

CONFIGURATION ANALYSIS



DESIGN REVIEWS

- PRELIMINARY (CONCEPT)
  - AFTER DESIGN CONCEPT, BEFORE DETAIL DESIGN
  - REVIEW INTERFACE DEFINITION
  - REVIEW AND EVALUATE DESIGN CONCEPTS
  - COMPARISON OF DESIGN APPROACH WITH REQUIREMENTS
  - REVIEW TRADE-OFFS
- CRITICAL (DETAIL)
  - 90 PERCENT DRAWING RELEASE
  - VERIFY PRODUCIBILITY OF DESIGN
  - EVALUATE TEST PROGRAMS
  - VERIFY DESIGN VS REQUIREMENTS
  - ESTABLISH READINESS TO FABRICATE/TEST HARDWARE
- FINAL
  - DESIGN COMPLETE/QUALIFICATION REPORT AVAILABLE
  - VERIFY HARDWARE READINESS
  - REVIEW MANUFACTURING PROCESS
  - EVALUATE RELIABILITY ANALYSIS
  - REVIEW QUAL TEST RESULTS
- UPDATE
  - ANYTIME
  - ANY COMBINATION OF ITEMS FROM OTHER THREE

PROGRAM QUALITY ASSURANCE ACTIVITIES

ACTIVITY	LMSC IMPLEMENTATION IN-HOUSE	SUB-CONTRACTORS	DESIGN & DEVELOPMENT	COMPONENT FAB, ASSY & TEST	SUBSYSTEM & SYSTEM ASSY & TEST	HOST VEHICLE INTEGRATION & TEST
SUPPLIER SELECTION	ANTICIPATE	APPROVE				
SUPPLIER QA REQUIREMENTS	DEVELOP	APPROVE				
INSPECTION TECHNOLOGY	DEVELOP	APPROVE				
INSPECTION & TEST PLANS	PREPARE	APPROVE				
COMPONENT TEST PROCEDURES	PREPARE	APPROVE				
TEST STATION PROOFING	PERFORM	APPROVE & WITNESS				
SOURCE SURVEILLANCE	N/A	RESIDENT				
INSPECTION	PERFORM	MONITOR				
TEST COMPONENTS	PERFORM	WITNESS				
TEST SYSTEM/ VEHICLE	WITNESS	N/A				
SYSTEMS TEST INSPECTION	PERFORM	N/A				
SYSTEMS TEST SURVEILLANCE	PERFORM	N/A				
NON-CONFORMANCE SYSTEM	MAINTAIN	APPROVE & MONITOR				
FAILURE REPORTING SYSTEM	MAINTAIN	MONITOR				
AUDITS - SUBCONTRACTOR	N/A	PERFORM		(6-12 MOS)		
AUDITS - PROCESS & OPEN BOX	PERFORM	PERFORM			(AS REQUIRED)	
COMPONENT DATA PKG REVIEW	PERFORM	PERFORM				
DD250 PACKAGE	PREPARE	N/A				

ACCEPTANCE DATA REVIEW

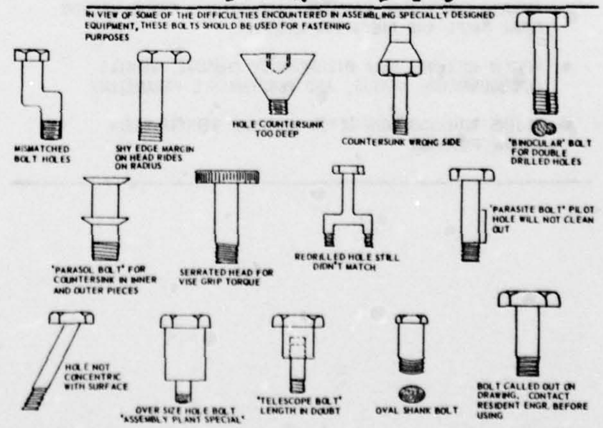
- ACCEPTANCE TEST COMPLETE
- PRODUCT ASSURANCE SUPPLIER REPRESENTATIVE (PASR) REVIEW COMPLETE
- PAINSTAKING EXAMINATION OF:
  - BUILD HISTORY DOCUMENTATION
  - SUBASSEMBLY TEST DATA
  - ACCEPTANCE TEST DATA
  - FAILURE DATA
  - ENGINEERING CHANGE INCORPORATION
- CRITERIA
  - COMPLETENESS AND SEQUENCE
  - ACCURACY AND LEGIBILITY
  - VERIFICATION OF PARTS TRACEABILITY INFORMATION
  - EVIDENCE OF INTERNAL CONTROL
- FAILURE DOCUMENTATION
  - DETAILS OF THE FAILURE
  - TROUBLESHOOTING AND ANALYSIS PROCEDURE
  - RESULTS OF FAILURE VERIFICATION
  - RESULTS OF STRESS ANALYSES
  - REPAIR INSTRUCTIONS
  - CORRECTIVE ACTION
  - ADEQUACY OF THE SPECIFIED RETEST
- SPECIAL ATTENTION FOR ITEMS DISPOSITIONED "USE-AS-IS"
- TECHNICAL ACCEPTANCE

HARDWARE AUDITS

- NORMALLY, ONE SCHEDULED PER BLOCK
- MAXIMUM VISIBILITY OF HARDWARE
  - AT LEAST ONE COMPLETED UNIT
  - COMPLETE SET OF SUBASSEMBLIES
- NOT A "DOG AND PONY" SHOW
- EXAMINE FOR:
  - WORKMANSHIP
  - INSPECTION
  - PROCEDURES
  - PROCESSES
- GOAL - REPEATABLE RELIABILITY
- NIT-PICKING!

LIVONIA BOLTS

IN VIEW OF SOME OF THE DIFFICULTIES ENCOUNTERED IN ASSEMBLING SPECIALLY DESIGNED EQUIPMENT, THESE BOLTS SHOULD BE USED FOR FASTENING PURPOSES



TEAM COMPOSITION

- DESIGN REVIEWS
  - CHAIRMAN, VEHICLE DESIGN INTEGRATION
  - RESPONSIBLE EQUIPMENT ENGINEER
  - RESPONSIBLE RELIABILITY ENGINEER
  - SYSTEMS ENGINEERING
  - PRODUCT ASSURANCE
  - SPECIALISTS AS REQUIRED, SPACE TECHNOLOGY,
  - MFG SYSTEMS ENGINEERING, ETC.
- N^{th} ARTICLE AUDITS
  - CHAIRMAN, VEHICLE DESIGN INTEGRATION
  - RESPONSIBLE EQUIPMENT ENGINEER
  - RESPONSIBLE RELIABILITY ENGINEER
  - PRODUCT ASSURANCE
  - MFG SYSTEMS ENGINEERING
- ACCEPTANCE DATA REVIEWS
  - CHAIRMAN, VEHICLE DESIGN INTEGRATION
  - RESPONSIBLE EQUIPMENT ENGINEER
  - RESPONSIBLE RELIABILITY ENGINEER
  - SYSTEMS ENGINEERING
  - PRODUCT ASSURANCE

SPACE VEHICLE CUSTOMER BUY-OFF RUNNING SELL

- RUNNING SELL CONCEPT ALLOWS CUSTOMER TO INCREMENTALLY ACCEPT THE SPACE VEHICLE
- PROVIDES CUSTOMER OPPORTUNITY TO ACHIEVE IN-DEPTH EVALUATION
- CUSTOMER REVIEW AND APPROVAL POINTS AFTER EACH MAJOR TEST COMPLETION I.E., COMPLETION OF FINAL ASSEMBLY, AMBIENT FUNCTIONAL BASELINE, ACOUSTIC, THERMAL VACUUM, FINAL PREPS AND PREPS FOR LAUNCH
- REVIEW INCLUDES DATA DISCREPANCY CLOSURE, VEHICLE CONFIGURATION, STATUS, AND PERFORMANCE PARAMETERS
- BEGINS BUILDING CONFIDENCE IN SPACE VEHICLE EARLY IN THE PROGRAM

KEY ELEMENTS FOR SUCCESSFUL REVIEW / AUDIT

- PROPER TIMING
- CAREFUL SELECTION OF TEAM
- SUPPORT OF SENIOR MANAGEMENT
- GOOD DEFINITION OF SCOPE/OBJECTIVES/GROUND RULES
- PRE-PLANNING
- CLEAR TEAM ASSIGNMENTS
- CHAIRMAN IN CHARGE
- FREE TO STATE FINDINGS
- NO BUILT-IN REQUIREMENT TO FIND PROBLEMS
- PRODUCT KNOWLEDGE AND INDEPENDENCE
- ATTENTION TO DETAIL

MANAGEMENT AND PROGRAM REVIEW PROCESS

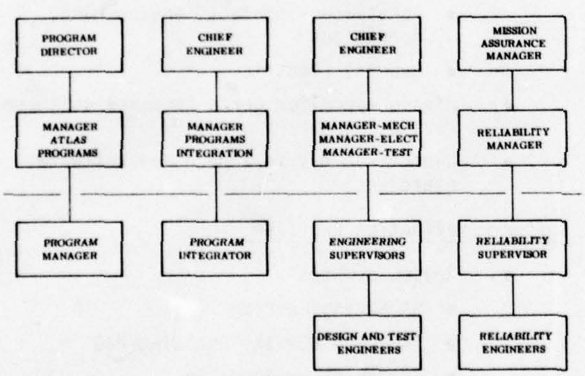
CONTRACTOR'S APPROACH TO INDEPENDENCE IN PROGRAM REVIEWS

Ben J. Wier
Manager, Atlas Programs
General Dynamics

ATLAS AND CENTAUR PROGRAM REVIEWS

MONTHLY	WEEKLY
• GENERAL MANAGER'S REVIEW	• TASK IMPLEMENTATION BOARD
• MISSION ASSURANCE (QUARTERLY)	• CHANGE BOARD
• QUALITY AND WORKMANSHIP REVIEW BOARD	• MANUFACTURING REVIEW
• PROGRAMS STATUS REVIEW	• LAUNCH VEHICLE RELIABILITY BOARD
	• PIECE PARTS CONTROL BOARD
ON-GOING	*REQUIRED BY PROGRAM*
• QUALITY ASSURANCE AUDITS	• REQUIREMENTS REVIEW
• MANUFACUTRING IN-PROCESS AUDIT	• PRELIMINARY DESIGN REVIEW
• FLIGHT HARDWARE CERTIFICATION BOARD	• CRITICAL DESIGN REVIEW
• ENGINEERING REVIEW BOARD	• FACTORY PRODUCT REVIEW TEAM
• SOFTWARE REVIEW BOARD	• FCA AND PCA
• PARTS DISASSEMBLY PROGRAM	• QAR REVIEW
• MATERIAL REVIEW BOARD	• SYSTEMS READINESS REVIEW
• MECHANICAL HARDWARE DISASSEMBLY AUDIT	• LAUNCH SITE PRODUCT REVIEW TEAM
	• *LAUNCH SUPPORT TEAM*
	• POST FLIGHT DATA REVIEW

LAUNCH VEHICLE PROGRAMS
INDEPENDENT REVIEW LEVELS



PDR and CDR

- PDR and CDR commit program to design
  - Current standards - rigorous and adequate
  - Provide independent assessments
    - Formal presentation
    - Documentation sent to review agencies two weeks before review
    - Formal minutes and action items

PDR and CDR Independent Participation

GDC

- Two levels of independence

SAMSO/Aerospace

- LV Engineering Office and Aerospace
- LV Operations Office and Aerospace
- LV Mission Assurance Office and Aerospace

SAMTEC

- 6595th Test Wing Operations and Aerospace
- SAMTEC Range Operations and FEC

SAMSO Payload Office

- Project Engineering and Aerospace

Others

- Payload Contractor
- NASA/Lewis
- NASA/Goddard

Quality Assurance Audit Team

- Twelve-man team
- Reports to Director, Quality Assurance
- All-inclusive charter
- In-house audits
  - Planning
  - Hardware
  - Processes
  - Test
  - Calibration
  - Mission assurance requirements
  - Special Audits
- Supplier audits
  - Planning
  - Hardware
  - Processes
  - Test
  - Calibration

Quality Assurance Audit Team Benefits

- Detect and report system deficiencies to management
- Shop personnel and inspectors more attentive to requirements
  - Improved detection of hardware discrepancies
  - Fewer hardware discrepancies
  - Better quality product
- Identify areas needing attention
- More realistic and explicit process spec requirements
- Better quality supplier hardware

Manufacturing In-Process Audit

- Electronic hardware
- Board level prior to assembly to package level
- Reviewed by
  - Designer
  - Packaging engineer
  - Test engineer

- Planner
- Technician
- Inspector

- Reviewed for
  - Design against functional requirements
  - Planning against required piece parts
  - Workmanship
  - Test data compliance
- Above reviews in addition to normal inspection buy-off

Hardware Acceptance Audit

- Product review team
  - Atlas SLV-3D product reviewed in factory and at launch site
  - Centaur product reviewed in factory and at launch site
  - Atlas F product reviewed in MAB and at launch site
  - All design disciplines and reliability represented
  - Perform to check list
  - Configuration documentation, QARs, test data, history jackets, procedures, parameters
  - Perform a walkdown of vehicle close to launch
- Review organization
  - Launch crew
  - All GDC design disciplines and reliability
  - SAMSO/LV and aerospace
  - 6595th Test Wing and Aerospace
  - NASA

Atlas Guidance Software Reviews

Trajectory and Guidance Working Group Meetings

- Group members
  - SAMSO - project and engineering
  - SAMTEC - 6595th Test Wing and Range Operations
  - NASA - Engineering Staff
  - Aerospace - Project and Engineering
  - Spacecraft/Upper Stage Contractors
  - General Electric - Gerts Guidance
- Review and approve trajectory and guidance system design and performance

Software Review Board (Atlas Guidance Station)

- Board members
  - SAMSO Engineering
  - Aerospace Engineering
  - SAMTEC 6595th Test Wing
  - General Electric
- Reviews and approves
  - Atlas guidance station software operations
  - Software design changes, implementation testing
  - Software configuration management and control

Software Data Review

- Review members
  - Aerospace technical staff
  - NASA technical staff
- Reviews and approves
  - Software testing requirements
  - Error analysis results
  - Trajectory simulation studies
  - Final targeting results

Atlas Guidance Station Review

- Review members
  - SAMSO - project engineering, operations
  - SAMTEC - 6595th Test Wing
  - Aerospace - project, engineering, operations
  - General Electric
- Mission-peculiar gerts hardware/software review
- Launch -30 day to launch day software exercises

Software Validation Exercise

- Review members
  - SAMSO engineering
  - SAMTEC - 6595th Test Wing/PJG
  - Aerospace engineering
- Formal mission-peculiar software tests at Atlas Guidance Station
- Validation results report published

Systems Review

- Review all launch vehicle systems, configurations, solutions to mission requirements, performance, software, supporting analyses. This is accomplished 30 days before erection of launch vehicle
- Review organization
  - GDC
    - Two levels of independence
  - SAMSO/Aerospace
    - LV Engineering Office and Aerospace
    - LV Operations Office and Aerospace
    - LV Mission Assurance Office and Aerospace

- SAMTEC
  - 6595th Test Wing Operations and Aerospace
  - SAMTEC Range Operations and FEC
- SAMSO Payload Office
  - Project engineering and Aerospace
- Others
  - Payload contractor
  - NASA/Lewis
  - NASA/Goddard

Stand Up and Be Counted

- Formal meeting with Director, Launch Vehicle Programs
- One week before launch
- Key engineering reliability, test and factory personnel, and management
- Each individual polled
- Any outstanding worry items

Observations on Government/Contractor Review Process

- Earlier scheduling of independent readiness review
  - Detracts from concentrating on the launch
  - Too little time for corrective action
  - Patches instead of fixes

Observations on Government/Contractor Review Process

- Proper selection of milestones
- Proper scheduling of milestones

Government/Contractor Review Process - In Depth and Rigorous

WORKSHOP SUMMARY

WORKSHOP SUMMARY

Workshop Objectives:

1. To define appropriate industry management involvement in descending review levels (line or staff) (to what depth) (prime management in subreviews).

2. To recommend appropriate timing for industry management participation in appropriate review levels.

3. To explore need for independence in the review process.

4. To define role and volue of special audits and Tiger Teams.

5. To evaluate usefulness of government review process and the timing of government reviews.

6. To recommend appropriate industry/government mix on review teams.

7. To determine if total government/industry review process is adequate or excessive for mission assurance.

Workshop Structure:

The morning session was devoted to briefings on the following topics:

1. Workshop Overview

   Speaker: Col. James A. Smith, SAMSO/CVI

2. The SAMSO Program Management Review Process

   Speaker: Lt. Col. Gordon Carpenter, SAMSO/AW

   The background and evolution of the Program Management Review Board was outlined and discussed. Topics included Pre-Contract Design Certification, Mission Readiness, Flight Readiness and Independent Mission Readiness Reviews. Command policy statements and other material which set forth the criteria and scope for the reviews was also presented.

3. Industry Corporate Visibility for Mission Success

   Speaker: Mr. Mark Sasso, RCA Astro Electronics

   Corporate policy and practices were outlined and discussed with respect to corporate reviews and audits with emphasis on the visibility to upper management, level of management involvement in various reviews, tools, techniques, methodologies, and other management vehicles used to provide a proper balance between Mission Assurance objectives and cost, schedule and performance goals.

4. Industry Mission Assurance Reviews and Audits

   Speakers: Mr. W.L. Finch, Lockheed Msls and Space Co.
   Mr. I.J. Wolf, Hughes Defense Sys Div.
   Mr. W.H. Shaw, TRW Defense & Space Sys Div.
   Mr. R.S. Wier, General Dynamics, Convair

   Industry Mission Assurance Practices and procedures were outlined and discussed. Discussions included objectives, scope, organization, audit types and schedules, checklist and other audit material. Significant areas stressed were:

   a. Depth in review process for various management levels, including the role of prime and submanagement levels.

   b. Timing for management involvement -- continuous or milestone.

   c. Need and timing for independent industry/government audits and reviews.

   d. Industry view of government review process.

5. Summary of Panel Objectives

   In the afternoon session, a panel comprised of the speakers and others having expertise in various related subjects accepted questions submitted on cards or expressed verbally. These were based on issues surfaced by the morning's presentation on other problems raised by panel members.

Lt. Col. G. Carpenter	SAMSO/AW
Mr. M. Sasso	RCA Astro Electronics
Mr. W.L. Finch	Lockheed Missiles & Space Systems
Mr. I.J. Wolf	Hughes Defense Systems Division
Mr. W.H. Shaw	TRW Defense & Space Systems Div.
Mr. R.S. Wier	General Dynamics, Convair Division
Col. K. Hughey	SAMSO/LV
Mr. M.V. Steel	Honeywell Avionics
Mr. R.E. Ciepiela	Martin Marietta
Mr. W.B. Botzong	RCA Astro Electronics

• **Problem/Issue**

Size of independent readiness review teams and personnel assignments are unsatisfactory. This condition also applies to the prime/sub relationship. Independent readiness reviews are not contractually applied. Current review schedules impact the contractors launch readiness preparations.

Solution/Action

Size of teams should be reduced commensurate with specific review parameters and more care should be taken in making personnel assignments. Personnel selected should not be removed too far from main stream of program. Requirements should be projected for non-interference with launch readiness activity. (This problem may already have been partially resolved through SAMSO pamphlet 800-11 which has not yet been communicated to all contractors.)

Responsible Agency - SAMSO/Contractors

- **Problem/Issue**

Independent review process timing is not optimized.

Solution/Action

Examine the possibility of establishing an independent design review as soon as possible in the CDR/PDR time frame. This area should be emphasized and should not interfere with additional activity as described in "running cell acceptance," "progressive acceptance," and "pedigree packages."

Responsible Agency - SAMSO/Contractor

- **Problem/Issue**

Launch readiness review should be treated as a process rather than an event.

Solution/Action

Use a system which is equivalent to LMSC's "running sell," the Hughes' "progressive acceptance" concept, and Martin Marietta's "pedigree package" concepts.

Responsible Agency - SAMSO/Contractor

- **Problem/Issue**

Flexible agenda - periodic management reviews, i.e., monthly/bi-monthly, often have rigorous contractually dictated agenda.

Solution/Action

Periodic management reviews should have a flexible agenda depending on status of program. Customer SPO director and contractor project manager have a pre-meeting to establish agenda and designate participants.

Responsible Agency- SAMSO

- **Problem/Issue**

Inadequate review preparation

Solution/Action

Review effectiveness can be improved by preplanning with the team and preparing reviewers with suggested techniques. Development of checklists may be part of this process. Reviews should be pre-scheduled and event-oriented. Team should be picked with good lead time. The review plan should be documented so that all team members, both contractor and government, can understand issues and objectives. Team meetings should be held to create criteria, checklists, types of questions to ask, and to prepare reviewers with techniques to be used.

Responsible Agency - Contractors

- **Problem Issue**

Special review debriefings: An adequate debriefing to those reviewed should be accomplished.

Solution/Action

Review groups should always document conclusions. Debrief responsible personnel, and be sure action item requirements are understood. Conclusions should be documented. Action items should be unambiguously assigned.

Responsible Agency - Contractors

- **Problem/Issue**

Transfer of technical review findings is unsatisfactory. This applies to both contractor and government special and independent readiness reviews.

Action/Solution

Cross program knowledge should be provided in non-proprietary areas between programs by both the government and the contractor.

Responsible Agency - SAMSO/Contractor

- **Problem/Issue**

Reviews are always added -- never deleted

Solution/Action

Review SAMSO Reg 800-3 for possible elimination of reviews due to redundancy or possibility of combining reviews. Assure those contractually specified are applicable and tailored to that contract.

Responsible Agency - SAMSO

WORKSHOP D

TECHNIQUES FOR MANAGEMENT AND CONTROL OF THE DEVELOPMENT AND APPLICATION OF SYSTEMS COMPUTER SOFTWARE

Co-Chairmen

Mr. Robert E. Berri
Member of the Technical Staff
The Aerospace Corporation

Dr. Eldred C. Nelson, Director
Technology Planning and Research
Systems Engineering and Integration Division

Workshop Coordinator

Mr. Dan Browne, SAMSO/AQ

AGENDA

Wednesday, April 26

0830-0845	Introduction	Mr. Robert E. Berri, Aerospace
0845-0915	Overview	Dr. Barry W. Boehm, TRW
0915-0945	SAMSO Software Environment	Mr. Robert E. Berri, Aerospace
0945-1000	Break	
1000-1030	FMEA for Software	Mr. Myron Lipow, TRW
1030-1100	Software Design Standards	Mr. James P. Chilton, MDAC
1100-1130	Software Quality Assurance	Mr. Harvey I. Gold, SDC
1130-1300	Lunch	
1300	Open Discussion	

INTRODUCTION

Mr. Robert E. Berri
Technical Staff
The Aerospace Corporation

Software Workshop Panelists

Len Anding	General Dynamics	QA
Dan Browne	SAMSO/AW	STE
Tom Burns	Hughes	STD
Clell Gladson	Contract Administration	MGMT
Shirley McCarty	Aerospace	STD
Leon Rue	Rockwell	FMEA
Al Schallenmuller	Martin Marietta	STD
Roger Sholten	Boeing	QA
Barry Zilin	SAMSO/PM	Procure

Summary Goals

- Define present SAMSO counterproductive practices or philosophies
- Make cost effective recommendations
- *Recommend* SAMSO operations standards
- Establish if there is a need for on-going sessions
  - Topics
  - Criticality
- Priorities of the above

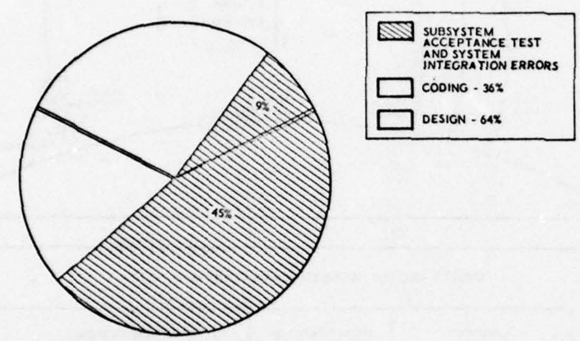
SOME KEY SOFTWARE ISSUES

Dr. Barry W. Boehm,
Director, Software Res and Tech
TRW

Outline

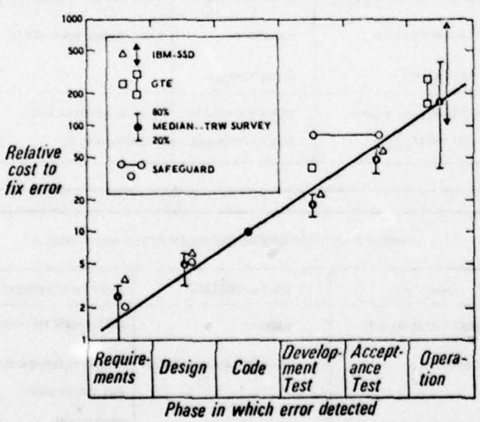
- General software mission assurance concerns
- Some specific SAMSO concerns
  - Present
  - Future
- Conclusions: an analogy

MOST SOFTWARE ERRORS ARE MADE IN DESIGN PHASE*

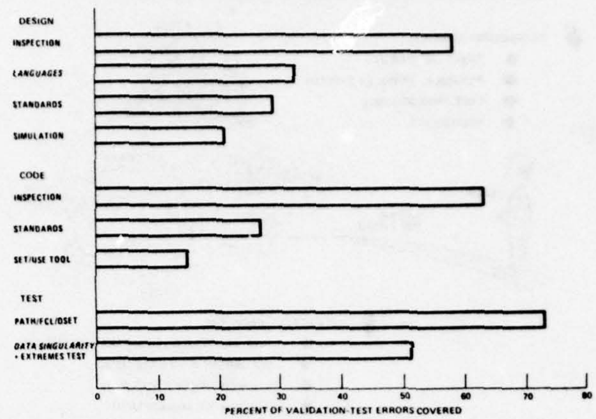


* TRW CCIP-85 DATA: 220 ERROR TYPES

REQUIREMENTS ERRORS MUST BE CAUGHT EARLY

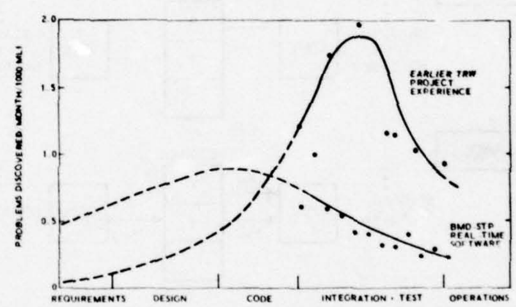


TECHNIQUES EXIST FOR CATCHING SOFTWARE ERRORS EARLY



GETTING ERRORS OUT EARLY - RESULTS

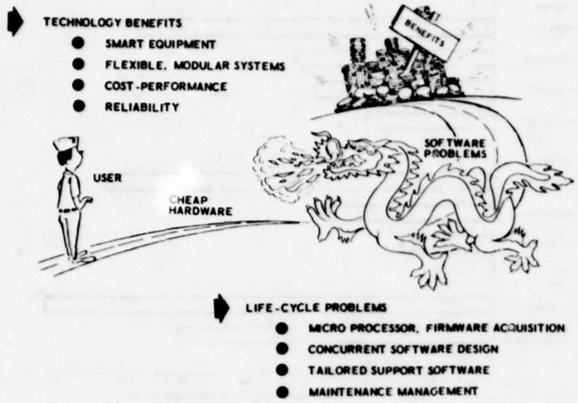
- REQUIREMENTS VALIDATION
- DESIGN VERIFICATION
- STANDARDS
- WALK-THROUGHS
- REVIEWS



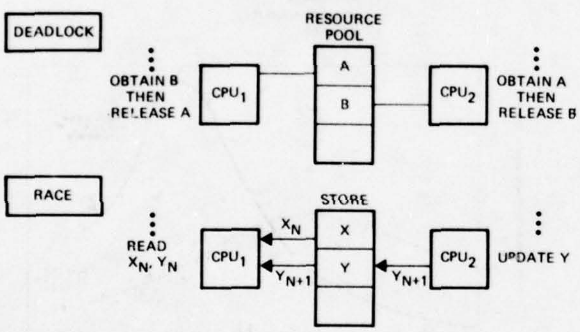
Some Specific SAMSO Concerns: Present

- Mission software problem causes and countermeasures
  - Interface problems
  - Data load problems
  - Control problems: who's in charge?
  - CM and QA problems
  - Off-nominal testing
  - Simulation and support software

SOFTWARE MANAGEMENT: WHERE ARE WE GOING?



DISTRIBUTED DATA PROCESSING HAS FUNDAMENTAL RELIABILITY PROBLEMS



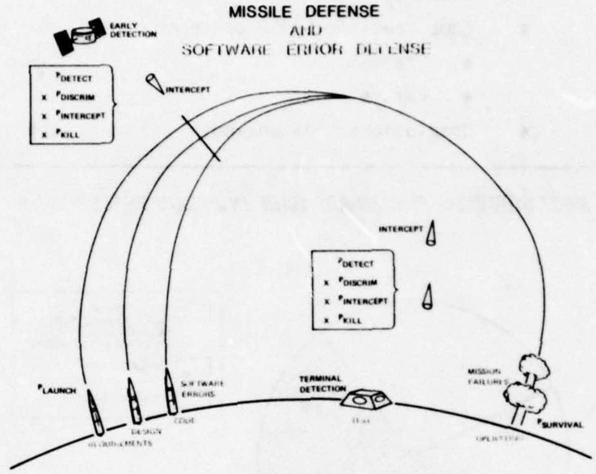
Distributed Data Processing Reliability: Key Issues

- How to detect, avoid deadlock and race problems
- How to instrument concurrent processors
- How to write DDP Specs, Acceptance criteria
- How to revalidate a modified DDP System
- How to specify appropriate standards
    - E.G., DoD-1

Microprogram Reliability: Key Issues

- How to detect and avoid adverse side conditions
- How to instrument microprograms
- How to assure fidelity of simulators + emulators
- How to detect and avoid low-level race problems
- How to determine appropriate level of firmware - life-cycle maintenance implications
- How to plan and carry out microprogram testing
- How to get better microprogram standards and "HOL's"

MISSILE DEFENSE AND SOFTWARE ERROR DEFENSE



MISSILE AND SOFTWARE ERROR DEFENSE MEASURES-I

OBJECTIVE	MISSILE DEFENSE	SOFTWARE ERROR DEFENSE
REDUCE P_{LAUNCH}	COUNTERFORCE SALT	LANGUAGES, STANDARDS, METHODS FOR REQUIREMENTS, DESIGN, PROGRAMMING
INCREASE EARLY P_{DETECT} $\times P_{DISCRIMINATION}$ $\times P_{INTERCEPT}$	SPACE SENSORS RADARS INTERCEPTORS	RQTS, DESIGN, CODE ANALYZERS WALK-THRUS, SIMULATION
INCREASE EARLY (AND TERMINAL) P_{KILL}	TERMINAL HOMING KILL MECHANISMS	REVALIDATION OF FIXES RIGOROUS CM, QA

MISSILE AND SOFTWARE ERROR DEFENSE MEASURES-II

OBJECTIVE	MISSILE DEFENSE	SOFTWARE ERROR DEFENSE
INCREASE TERMINAL P_{DETECT}	RADARS GROUND, SPACE SENSORS	TEST, PROOF METHODS STRESS TESTING CONCEPTS AUTO. TEST AIDS EMULATION
INCREASE TERMINAL $P_{DISCRIMINATION}$ $\times P_{INTERCEPT}$	RADARS, OTHER SENSORS INTERCEPTORS	DIAGNOSTIC TEST TOOLS DIAGNOSTIC EMULATION
INCREASE $P_{SURVIVAL}$	HARDENING DECOYS MOBILITY	FMEA FAULT TOLERANCE

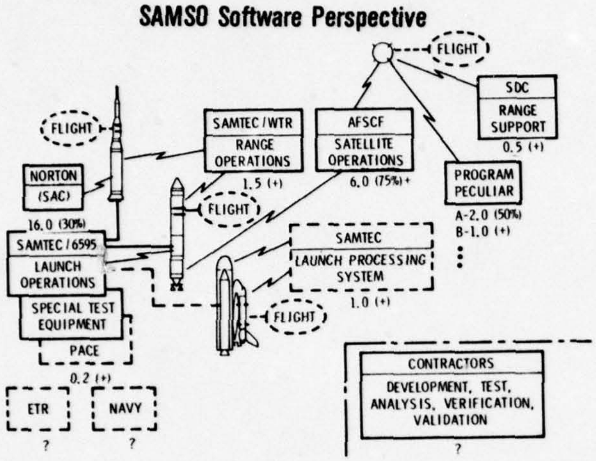
Some Observations About Software Error Defense

- Overemphasis on terminal defense (testing)
- Need more effort on:
  - Reducing error launch rate
  - Increasing early detection → elimination capabilities
  - Increasing probability of surviving effects of errors
- Need more effort in threat analysis
  - Comparable to intelligence budget
  - Study implications of new technology (micros, firmware, DDP, MCF, DoD-1)
- Need a focal point of responsibility

SAMSO SOFTWARE ENVIRONMENT

Mr. Robert E. Berri
Technical Staff
The Aerospace Corporation

SAMSO Software Perspective



Issues

- Should SAMSO standardize/control launch environment?
  - Software
  - Special test equipment
- Can range (SAMTEC/AFSCF) interfaces be improved?
- Should computer resources working groups be utilized?
  - Membership
  - Functions
- How extensively should test plans/procedures be reviewed?
- Is independent V&V cost effective?
- Should internal (e.g., analysis) software be more portable?

FAILURE MODES AND EFFECTS ANALYSIS
FOR SOFTWARE

Myron Lipow
Sr. Staff Engineer
TRW

M. Lipow
A. Frimtzis
D. Reifer

Software Failure Modes and Effects Analysis Topics:

- The purposes of FMEA - definitions
- Prevention of failure modes
- Compensating features for single point failure modes
- Fault tolerance features

The Purposes of FMEA:

- To identify, rank, and compensate for failure modes of critical functions
- As a tool for design evaluation and test planning
- To provide input to reliability, maintainability, and safety analysis

Classification of Failure Modes

- Hardware-induced hardware failure modes and effects - SAMSO 77-2
- *Software-induced hardware* failure modes and effects - SAMSO 77-2
  - Logic error results in arming fuze at wrong altitude or not at all - SAMSO 77-2
- Hardware-induced software failure modes and effects
  - Transient spike results in abnormal input data
- Software-induced software failure modes and effects
  - Poor algorithm approximation results in out of tolerance computation

Software FMEA

- Definitions
  - Software - computer programs + data
  - Failure mode - manner in which failure occurs
  - Examples:
    - Program aborts
    - Program degrades
    - Program loops indefinitely
  - Failure effect - consequence(s) of the failure mode
  - Single point failure - at any level, the failure of which would result in irreversible degradation of mission performance, or prevent achievement of a mission objective

Purpose and Application of the FMEA (SAMSO-STD-77-2):

1. To identify all failure modes-mission effects-corrective/compensating action
2. To identify single point failure modes
3. To identify critical functions for redundancy
4. To identify compensating features
5. To identify untestable redundant areas
6. To aid in identifying untestable functions
7. To rank most serious failure modes
8. To establish a critical items list
9. To form an input to reliability modeling and predictions
10. Iterative design tool
11. Evaluation design tool
12 Diagnostic tool
13. Test planning criterion
14. Determining operational constraints
15. Aid in maintainability, safety, hazards analysis
16. Identify problem areas to be avoided in manufacturing.

Potential Failure Modes Introduced in Design and Coding

- Requirements incomplete or ambiguous leading to deficient design
- Coding practices (lack of standards, inspection) leading to difficult-to-detect faults
- Non-robust algorithms
  - Fail to converge
  - Converge at sub-optimal points
- Deadlock - in distributed processors - problem because of inadequate memory margin

SOFTWARE FAULT TOLERANCE

- SELF-CHECKING SOFTWARE
- REDUNDANT SOFTWARE

EXAMPLE: G&C SYSTEM

16K BASIC PROGRAM	18K ADD: INSTRUMENTATION	33K ADD: REDUNDANCY
SINGLE POINT FAILURE MODES	HEALTH AND STATUS CHECKING IN REAL TIME	REDUNDANT SOFTWARE WITH SWITCHING LOGIC
	INFORMED MANUAL RECOVERY POSSIBLE	MAY NOT PROVIDE ALL FUNCTIONS

- AEROSPACE STUDY OF FLIGHT CONTROL SOFTWARE
  - 30% MORE STORAGE
  - 10% MORE EXECUTION TIME

Compensating Features for Single Point Failure Modes

To reduce the probabilities of single point failure modes to acceptable values.

How? Techniques and tools to prevent/detect errors/faults.

- Design
  - Top-down - stepwise refinement
  - Requirements verification/ traceability systems
  - Program design language
  - Design walkthroughs
- Programming
  - Standards - compliance tool
  - Structured programming - e.g., S-Fortran
  - Code walkthroughs
  - Static analyses
    - Set-use checker
    - Units consistency checker
    - Phantom path analysis - complexity assessment and reduction
- Testing
  - Frequency of loop usage
  - Aids to identify test cases
  - Interpretive computer simulation-timing
  - Nuclear safety cross-check analysis (NSCCA)

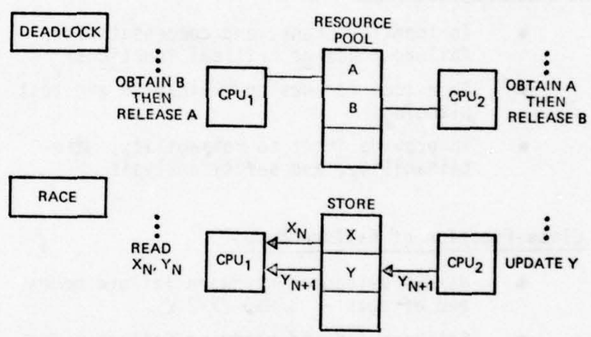
Preventing Failure Modes for the Minuteman Missile System Software (Independent V&V Contractor)

- Nuclear safety cross-check analysis (NSCCA)
- Performance and technical evaluation (PATE)

NSCCA
- Unauthorized or inadvertent launch
- Premature launch
- Unauthorized display of classified information
- Faulty launch
- Invalid verification of codes

PATE
- Satisfaction of program specifications
- Extremes testing
- Program does not degrade subsystem capability

DISTRIBUTED DATA PROCESSING HAS FUNDAMENTAL RELIABILITY PROBLEMS



Research Directions

Near-Term

- Modify MIL-STD-1543 and SAMSO Standard 77-2 to include software FMEA
- Analyze RADC/IS software reliability data base to determine failure modes
- Identify how software FMEA can be used as part of system reliability analysis

Long-Term

- Identify design and verification and validation practices needed to reduce failure modes
- Identify certification procedures that can be used and related facility concepts (simulators, emulators, etc.)
- Develop a system reliability model concept that includes the incremental contribution of software

SOFTWARE DESIGN STANDARDS

James P. Chilton
Director, Data Processing Sys Tech Prgms
McDonnell Douglas Astronautics Company

Air Force Software Concerns

- Significant and growing problem
  - Lack of controls
  - Black art
- Difficult to verify
- Training needed
  - Government
  - Industry
- Should have same disciplines that are applied to hardware
- Applies to both deliverable and non-deliverable

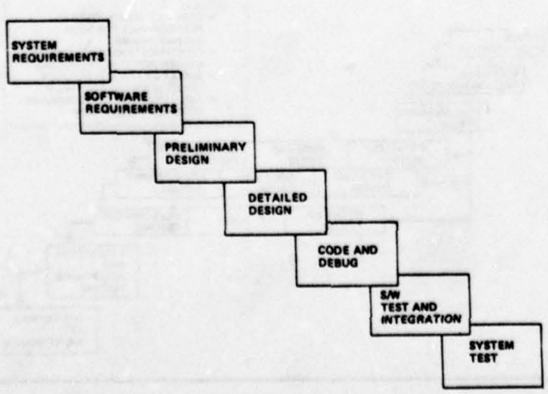
What Can We Do To Assure Successful Software?

- Management actions
- Development approach
- Quality assurance

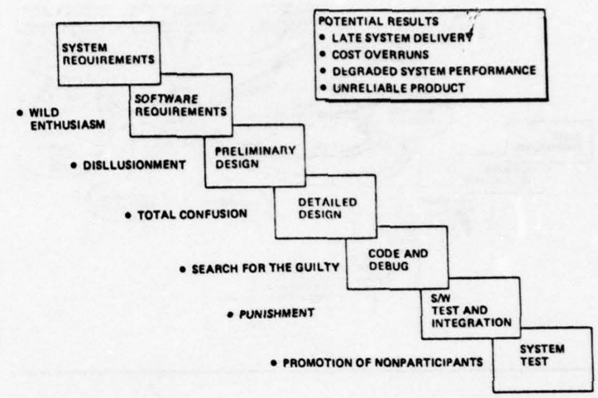
Management Actions

- Recognize that software is a product and can be manufactured
- Establish disciplined development approach
- Establish management controls
- Plan quality assurance from the start

SOFTWARE DEVELOPMENT APPROACH



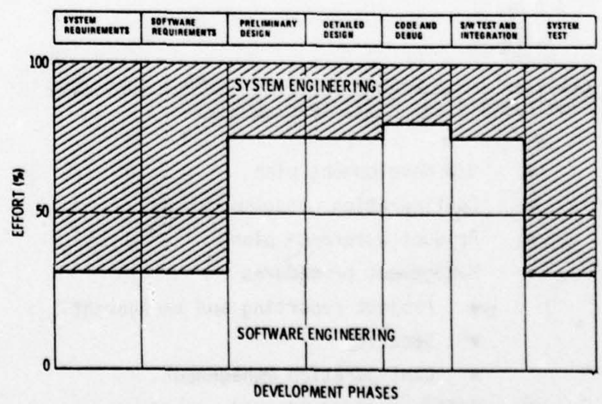
SOFTWARE DEVELOPMENT APPROACH



Key Elements of Software Development Approach

- Software development team
- Software requirements
- Setting software design baseline
- Plans, procedures, standards
- Top down design and implementation
- Design reviews and visibility
- Documentation and traceability
- Configuration management
- Testing

SOFTWARE DEVELOPMENT TEAM

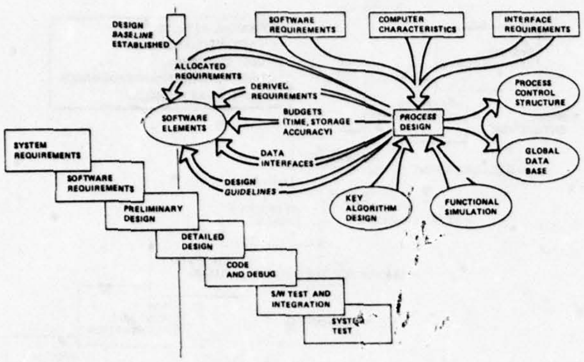


Software Requirements

- Represent the system design solution
- Can be determined only as part of the engineering of the system
- Are the basis for defining the desired implementation to the software developer
- Must be testable

PRELIMINARY DESIGN

THE DOWNWARD ALLOCATION OF REQUIREMENTS AND DESIGN TO A SOFTWARE STRUCTURE



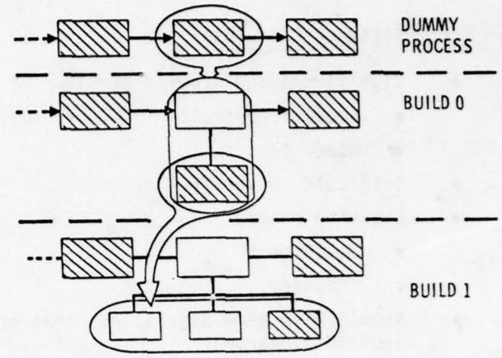
<u>Complete Preliminary Design Forces Establishment of a Sound Development Baseline</u>

- Provides solid software design feedback to customer/system designers
- Provides software structure for managing detail design
- Establishes the capability of the process structure to accommodate change
- Determines port-to-port responses in a realistic environment - under load
- Establishes adequacy of interface design
- Establishes that the operating system and development support software will support the applications programs

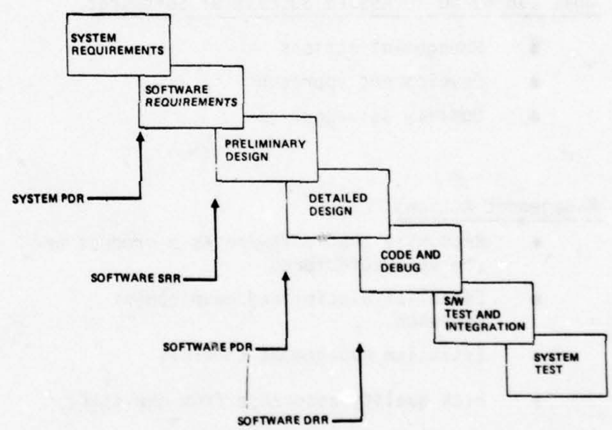
<u>Establishing a Design Baseline is More Than Just Requirements and Preliminary Design</u>

- S/W development plan
- Configuration management plan
- Product assurance plan
- Management procedures
  - Project reporting and management
  - Security
  - Configuration management
- Software standards and procedures
  - Naming conventions
  - Programming standards
  - Documentation conventions
  - Unit test criteria
- Software quality manual
- Software validation test plan

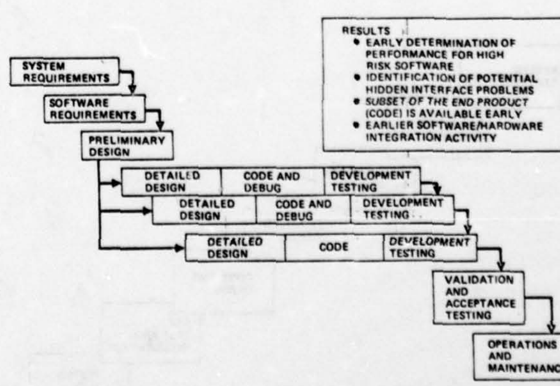
IMPLEMENT THE SOFTWARE FROM THE TOP DOWN



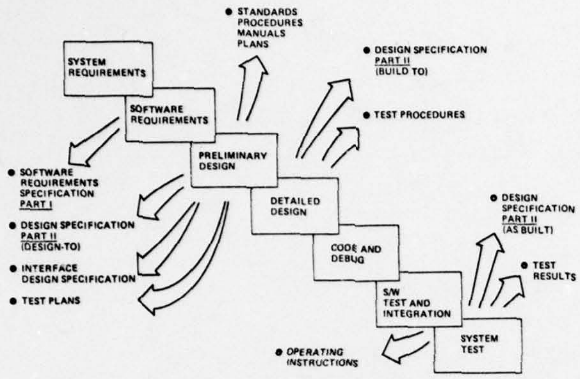
DESIGN REVIEWS



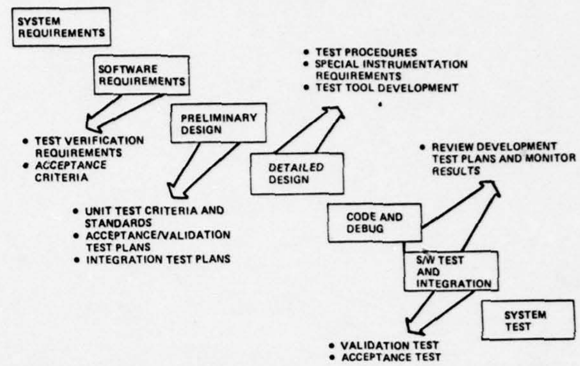
DEVELOP SOFTWARE INCREMENTALLY TO MINIMIZE RISK



DOCUMENTATION



DON'T LEAVE YOUR TEST PLANNING TO THE END



Configuration Management

- All computer programs progress through an ordered set of baselines consistent with program schedules
- Approved software requirements and interface specifications are the basic design requirements
- Software baselines include requirements, design, code and product representing progressively more stringent levels of control
- Changes must be approved by the appropriate change control board

LEVEL OF PRODUCT CONTROL VARIES WITH DEVELOPMENT PHASE

OCL	REQUIREMENTS	PREL DES	DET DES	CODE C/O	PROCESS INTEG	PROCESS VALID.	SYS I/T
PROGRAM MANAGER	X						X
SOFTWARE MANAGER	X					X	
PROCESS MANAGER		X	X	X	X		
TASK MANAGER			X	X			
ROUTINE MANAGER							
ROUTINE MANAGER							
⋮							
TASK MANAGER			X	X			
ROUTINE MANAGER							
ROUTINE MANAGER							
⋮							
TASK MANAGER			X	X			
⋮							

Quality Assurance

- Separate function
- Participate in review of documentation, standards and procedures
- Utilize automated tools to verify compliance with standards and procedures
- CCB participant
- Verify test criteria compliance
- Verify content of delivered product

Conclusions

- A disciplined approach
- Enforced by management
- With appropriate visibility and controls
- Results in successful software which
  - Performs its required functions
  - Under prescribed conditions
  - On cost
  - On schedule

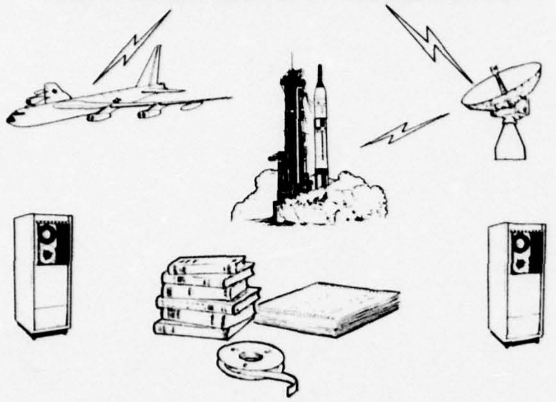
Discussion Points

- Value of a disciplined approach
- Value of government imposed regulations to software quality
- Cost of having standards versus guidelines
- Cost of visibility and is it worth it
- When and where is quality assurance most effective in achieving quality software

SOFTWARE QUALITY ASSURANCE

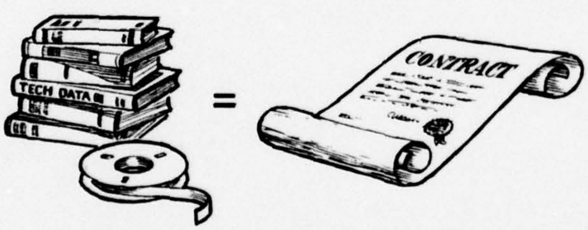
Mr. Harvey I. Gold
Department Manager
System Development Corporation

SOFTWARE QUALITY ASSURANCE



DEFINITIONS

QUALITY ASSURANCE



SOFTWARE QUALITY ASSURANCE

CM	USE OF RESOURCES	DESIGN & DEVELOPMENT	TESTING	CORRECTIVE ACTION	LIBRARY CONTROLS	DOCUMENTS	REVIEWS & AUDITS
TOOLS — TECHNIQUES — PROCEDURES — METHODOLOGIES							

IMPLEMENTING THE CONTRACTOR's QUALITY ASSURANCE PROGRAM

- MIL S 52779
  - REQUIRES A SOFTWARE QA PROGRAM TO ASSURE THAT ALL SOFTWARE PRODUCTS MEET ALL CONTRACTUAL REQUIREMENTS
- RFP REQUIRES SOFTWARE QA
  - SHOULD BEGIN IN VALIDATION PHASE
  - QA PLAN PART OF THE CPDP
- CONTRACTOR'S QA PROGRAM ADDRESSES:
  - WORK TASKING & AUTHORIZATION PROCEDURES
  - CONFIGURATION MANAGEMENT
  - TESTING & TESTABILITY
  - CORRECTIVE ACTION
  - LIBRARY CONTROLS
  - COMPUTER PROGRAM DESIGN
  - SOFTWARE DOCUMENTATION
  - REVIEWS & AUDITS
  - TOOLS, TECHNIQUES & METHODOLOGIES
  - SUBCONTRACTOR CONTROL

PLANNING THE CONTRACTOR's QUALITY ASSURANCE PROGRAM

AUTHORITY

- MUST BE INDEPENDENT

RESOURCE ESTIMATION

- BASED ON DETAILED ANALYSIS OF TASKS
- RULE OF THUMB 3–5%

PLAN

- NEEDS DETAILED SCHEDULES AND MILESTONES
- RELIES ON QA PROCEDURES AND STANDARDS
- ADDRESSES ORGANIZATIONAL RELATIONSHIPS

PERSONNEL QUALIFICATIONS

HELP WANTED

POSITION - SOFTWARE QUALITY ASSURANCE STAFF

QUALIFICATIONS -

EXPERIENCE IN FOLLOWING AREAS:

- MILITARY OPERATIONS KNOWLEDGE
- SOFTWARE AQUISITION MANAGEMENT
- CONFIGURATION MANAGEMENT
- DATA MANAGEMENT
- RELATED MILITARY SPECIFICATIONS & STANDARDS
- TECHNICAL EXPERIENCE IN SOFTWARE DEVELOPMENT
- CONTRACTING/SUBCONTRACTING
- TEST MANAGEMENT
- SOFTWARE ENGINEERING MANAGEMENT

QA - Organizational Independence

- All responsive QA organizations are independent
- Some important organizational issues:
  - Is QA a line or a staff function?
  - Who does QA report to?
  - What authority (or power) does QA have?
  - Adversary or cooperative role?

RELATIONSHIP TO TESTING

	GOVERNMENT (CUSTOMER)	DEVELOPMENT CONTRACTOR	INDEPENDENT CONTRACTOR
SETD			√
DEVELOPMENT TEST		√	
INDEPENDENT TEST		√	√
QA	√	√	

- QA REVIEWS AND EVALUATES THE TEST PROCESS & PRODUCTS
- QA DOES <u>NOT</u> DO TESTING

Discrepancy Reporting/Correction

- Should QA:
  - Report problems?
  - Maintain problem status?
  - Correct problems?
- QA should:
  - Evaluate problem handling plans
  - Evaluate the process
  - Produce QA evaluation reports
  - Maintain QA records

Software QA Can Pay Huge Dividends

- Early assessment of risk
- Must include performance cost and schedule
- Must address process as well as products
- Must focus on early products
  - Contract
  - Plans and schedules
  - Specifications (A and B)

WORKSHOP SUMMARY

WORKSHOP SUMMARY

Issues Raised and Discussed

Issues raised by the speakers and discussed by the panels are summarized below. Because some of the issues were common to several of the topic areas, the issues are presented as software mission assurance issues rather than associating them with specific topic areas.

1. Software errors affecting mission assurance frequently originate in requirements and design phases; therefore software errors should be addressed in these phases. Use of new techniques and tools supporting the identification and analysis of these errors - e.g., requirements validation, design verification, standards, walk throughs, and reviews - should be encouraged by SAMSO.

2. Testing limited to nominal specification values tends to be inadequate. Test strategy should include consideration of extreme and singular points.

3. SAMSO needs an organization like the AFSC/XRF Computer Resources Committee - to initiate SAMSO software standards, transfer lessons learned, and review computer resource acquisition.

4. SPO's should be better informed on how software can affect mission assurance. Data on software failure history in space and missile systems is needed. Analysis of the software data base collected by RADC may help.

5. Should project management plans be contract compliance documents? Although opinions were divergent on this issue, it was agreed that such plans are valuable management aids to both SAMSO and the contractor. Their use should be encouraged.

6. Hazard analysis using FMEA techniques and simulations should contribute to mission assurance. SAMSO Standard 77-2 should be modified to include software.

7. A limited version of configuration management and quality assurance should be imposed on software test tools.

8. Upper management (both SAMSO and contractors) need to better understand the software development process and its role in system development. A management education program on software needs to be developed.

9. SPO planning generally fails to recognize logistic support and operational use problems, particularly as they affect software. Such considerations should be addressed in the system concept phase.

10. The software design phase can benefit from effective management and should include test planning and consideration of operational use procedures.

11. SAMSO review of contracts should be strengthened to assure (a) adequacy of software requirements such that they are complete, clear, unambiguous, and understood by both parties, (b) invocation of recent policy on configuration management, modern programming practices, and design reviews, and (c) adequate use of management plans.

12. Software quality assurance can contribute to mission assurance. SAMSO needs to define what is required of the contractor.

13. MIL-S-52779, when tailored by SAMSO P 74-2, is a good frame of reference for quality assurance, but is needs to be modified to deal more specifically with software needs.

ISSUES RAISED BUT NOT DISCUSSED

Owing to lack of time and to the focus of interest of the Workshop attendees, some of the issues raised by the speakers were not discussed, to any degree, by the panels and the audience. These issues are summarized here:

1. The AFPRO role in monitoring software development – e.g., with respect to design standards, intermediate testing, (PQT) monitoring, and configuration management – could be strengthened.

2. Distributed processing, particularly in systems involving microprocessors, introduces new problems affecting mission assurance – e.g., race conditions and deadlock.

3. SAMSO launch control areas are essentially program peculiar. Could standardization of this environment be accomplished, benefiting both hardware and software development?

4. Interfaces between SPO's SAMTEC, and AFSCF appear to not be well defined. Is an improvement necessary?

5. Since software in embedded computer systems generally has not been tested as a configuration item, should more extensive software testing be required?

6. Is independent verification and validation effective for SAMSO programs?

7. SAMSO contractors utilize extensive internally developed development support software. Since some of this is believed to be redundant, should SAMSO require delivery and/or portability of it?

8. Because major change orders (ECPs) can be processed at SAMSO without adequate staff review, their effect on mission assurance may not always be considered. Is better control needed?

9. A system reliability model including the software contribution is needed.

10. Better methods of verification, validation, and certification are needed to reduce failure modes.

11. Contracts tend to overconstrain contractors.

12. Are there cost advantages in not imposing software design standards?

13. What should be the relative role of software quality assurance and software testing?

Principal software development problems affecting mission assurance are management problems

Reviews do not adequately address issues affecting mission assurance

Cost Saving Actions at Procurement Time

- On:
  - Documentation
  - Test
  - QA Functions
- Frequently increase mission assurance problems

Software Workshop Recommendations

SAMSO should establish counterpart of DSARC reviews

- To address software issues affecting mission assurance

SAMSO should strengthen role and resources of

- Focal point for computer resources

Software life cycle cost and logistic support

- Should be considered at concept stage
- Need software life cycle cost model

Follow-on session desireable

WORKSHOP E

SUBCONTRACTOR INTERFACE & CONTROL TO ACHIEVE MISSION ASSURANCE

Co-Chairmen

Lt. Col. Richard E. Tracey Chief of Reliability & QA ICBM Program Office	Mr. Howard C. Ringoen Director Material Boeing Aerospace Co.

AGENDA

Wednesday, April 26,

0830-0845	Introductions, Objectives, Agenda	Mr. Howard C. Ringoen, Boeing Mr. Richard D.K. Goo, SAMSO/MNCP
0845-0915	Procurement Trends in Small and Minority Business	Mr. Eutimio B. Romero, Boeing Co.
0915-0945	Controlling the Independent, Profit Motivated Subcontractor	Mr. Peter H. Fowler, TRW Systems
0945-1015	Break	
1015-1045	Critical Elements in Supplier Control	Mr. Marion Smith, Honeywell, Inc.
1945-1115	Comments	Attendees
1115-1315	Assignments for Afternoon Panel Discussions	
1315-1600	Panel Discussions	
1600	Panel Conclusions and Recomendations	

Discussion Moderators:

Mr. Andy Myers	Martin Marietta Aerospace
Mr. Pete Fowler	TRW Systems
Mr. Marion Smith	Honeywell Inc.

Overall Objective:

To provide a forum for open and frank dialogue between the Government and Industry on specific subcontractor problems and concerns, the correction or improvement of which will provide greater mission assurance.

Specific Goals:

1. To define present SAMSO practices or philosophies that are counterproductive
2. To develop recommendations that will provide cost effective mission assurance
3. To define recommended standards of operation
4. To define requirements for on-going studies

WORKSHOP E (continued)

Specific Areas to be Discussed by each Panel where Improvements would Enhance Mission Assurance

1. Flow down of motivation (fees/disengagement)
2. Flow down of critical parameters, considerations and design requirements
3. Selecting the subcontractor/supplier
4. Pre-award, post-award and facility capability surveys (audits)
5. Optimizing source acceptance
6. Monitored fabrication lines (process controls)/coordinated procurements
7. Visibility and trust in subcontractor/supplier operations/relations (types of contracts)
8. Small lot, high-reliability buying options
9. Material review boards, preliminary reviews and corrective action
10. Other

CURRENT SMALL/MINORITY BUSINESS TRENDS IN PROCUREMENT

Mr. Eutimio B. Romero
Boeing Company

- Established small/minority business programs
- Industry approach
- Environment
- Concerns
- Conclusions

Small Business Definition

A small business concern is independently owned and operated, is not dominant in the field of operations in which it is bidding, and with its affiliates, can further qualify under the criteria set forth in ASPR 1-701 or NASA PR 1-701. "Concern" means any business entity organized for profit with a place of business in the United States, its possessions, Puerto Rico, or the Trust Territory of the Pacific Islands, including but not limited to an individual partnership, corporation, joint venture, association, or cooperative.

Minority Firm Definition

The term "minority business enterprise" means a business, at least 50 percent of which is owned by minority group members or, in case of publicly owned businesses, at least 51 percent of the stock of which is owned by minority group members. For the purposes of this definition, minority group members are American Blacks, Spanish-speaking American persons, American Orientals, American Indians, American Eskimos, and Americal Aleuts.

Contractual Obligations (ASPR 1-700)

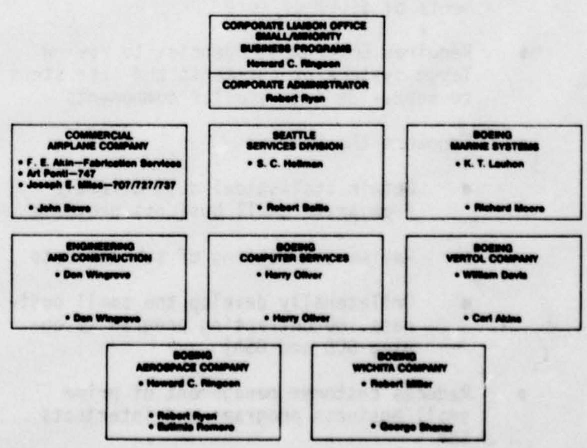
Contractor will — assume an affirmative obligation with respect to subcontracting with small business ... ASPR 1-707-2

- Designate a liaison officer/administrator
- Consider in make/buy decisions
- Assure equitable opportunity to compete, particularly by actions to facilitate participation
- Request SBA to locate sources when over $10K and no small business sources known
- Incorporate small-business clause in all subcontracts that offer substantial opportunity
    - $10K-$500K – maximum effort
    - Over $500K – establish formal program
- Notify contracting officer of awards of $500K or more
- Cooperate with contracting officer in studies and surveys
- Submit quarterly reports to Government
- Contract may be terminated for failure to comply
- Maintain records
    - Size of suppliers
    - Procedures for complying with this clause
    - Purchase of contracts $10K and up, whether
        - Awarded to large or small business
        - Number of small businesses solicited
        - Reasons for not soliciting small businesses
        - Reasons small businesses failed to receive award when solicited

Corporate Policy

- It is Boeing policy not only to comply with its contractual obligation, but also to place a fair proportion of its total purchases for materials, supplies, and services with small businesses, minority-owned businesses, and labor surplus area concerns.
- Special efforts will be made to encourage these firms and to give them the opportunity to compete.

Although our compliance with Government contracts is critical, it is our total company performance in all divisions of the company that tends to establish our credibility and reputation.



Environment

High level and high degree of attention in all quarters.

- Minority and small business pressure groups
  - NABM – National Association of Black Manufacturers
  - BCPNE – Black Corporation Presidents of New England
  - LAMA – Latin American Manufacturers Association
  - SBANE – Small Business Association of New England
  - COSIBA – Council of Small and Independent Business Association
  - SBLC – Small Business Legislative Council
- Industry pressure groups
  - NMPC – National Minority Purchasing Council (private sector voluntary movement)
  - Congress
    - Black Caucus
    - Committee changes
    - GAO report – DOD minority program
    - Legislation
      - Senate Bill 2259
      - House Bill 11318

Senate Bill 2259 (Senator Gaylord Nelson)

- Establishes written small business subcontracting plans on Government procurements of \$500K or more
- Requires Government agencies to review large systems procurements and take steps to subdivide into smaller components
- Empowers the SBA to:
  - Obtain statistical data directly from prime small business programs
  - Review the letting of subcontracts
  - Unilaterally develop the small business subcontracting program (dropping DOD and GSA)
- Reduces customer management of prime small business programs and interjects SBA

House Resolution 11318
(Congressman Joseph Addabbo)

- Replaces many draft bills, including HR 567, the Minority Business Act of 1977 (Parren Mitchell)
- Does not include the 2 percent or 5 percent requirement
- Introduces a "socially and economically disadvantaged" definition, which means that
  - 51 percent ownership is by socially and economically disadvantaged groups or individuals, including American Black, Hispanic American, and any other minority or individual found to be disadvantaged by the Administration
  - Management and control of the business is by such person or persons
  - The SBA may find, on basis of evidence, that an individual group is not disadvantaged
  - The SBA may add others to the disadvantaged list
  - The SBA may deny assistance if it determines that competitive viability cannot be achieved within a reasonable period of time
- Requires written subcontracting plans for procurements of \$1,000K if for construction of any public facility or \$500K for any other purpose. The final plan becomes contractual.

Environment

- Government agencies
  - All pushing
  - Increased surveillance
  - Nonregulatory proposal requirements
    - Written subcontracting plan identifying items and minority suppliers
    - Goals

Concerns

- Written subcontracting plans
- Breakouts
- Minority business base
- Reports – Goals
- DOD/NASA responsiveness to major contractor problems – help needed

Conclusions

- Government and major contractors need to reestablish a "single" program
- Topside pressure is not an effective approach to develop a better small/minority business base.
- The approach being used to develop the small/minority business base may not be adequate

CONTROLLING THE INDEPENDENT PROFIT MOTIVATED SUBCONTRACTOR

Mr. Peter H. Fowler
Subcontract Manager
TRW

The Environment

In

- High ROI — more subcontracting
- Stable, predictable business
- Large market share — only the first three viable
- Low profile — play down defense and aerospace

Out

- Growth as an independent objective
- Loss leaders
- Technology for its own sake
- Paperwork

Article I — Scope of Work

The seller, as an independent subcontractor and not as an agent of the buyer, shall .....

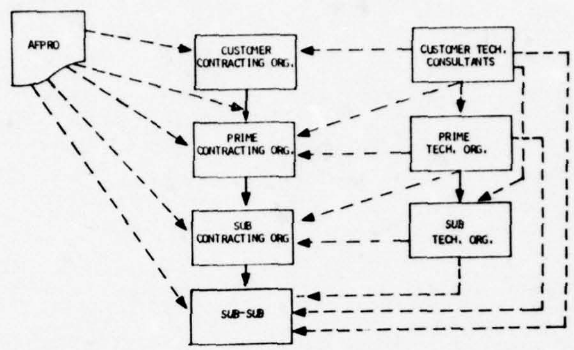
Duties of Management of Subcontractor

- Act always in the best interests of the stockholders
- Make a profit (meet ROI target)
- Maintain the organization

MOTIVATIONS

MOTIVATING FACTOR	RESPONSE	EFFECT ON PERFORMANCE	RESPONSE BY PRIME
MAXIMIZE RETURN	O MINIMIZE COST	O MAXIMIZE RISK	O ELABORATE SOW
	O MEET SPEC MARGINALLY	O MAXIMIZE RISK	O OVER SPEC
	O MINIMIZE QUALITY	O JEOPARDIZE SCHEDULE & OBJECTIVES	O SOURCE INSPECTION
	O SUBCONTRACT	O REDUCE VISIBILITY	O "FLOW DOWN"
STAY IN BUSINESS	O DEVELOP REPUTATION	O HIGHER COSTS	O GET MORE COMPETITORS
	O COOPERATE WITH PRIME	O RAISES COST, JEOPARDIZE SCHEDULE	O SCHIZOPHRENIA
	O MAKE A PROFIT	O RAISES COSTS	O NEGOTIATE HARDER
	O KEEP COSTS DOWN	O SELECTIVE CONTRACTING	O REDUCE REQUIREMENTS

PRIVITY OF CONTRACT (WHO'S IN CHARGE HERE)



Assure What?

	Typical Satellite Problems	Typical Response
•	Ground testing misses space environmental problems	More inspection
•	Test data overwhelms review (problems missed)	More data taken
•	Design beyond experience	Tighter control

The Nature of the Problem

- Management of conflict
- Clarification of roles
- Recognition of humanity
- Appropriateness of reaction

The Problem

How to gain assurance without taking control.

CRITICAL ELEMENTS IN SUPPLIER CONTROL

Marion P. Smith
Manager, Material Quality Assurance
Honeywell Inc.

To meet mission assurance requirements certain elements are critical –

- Identify and place the essential requirements on the supplier
- Establish and maintain a meaningful assessment of supplier performance
- Keep the loop closed on supplier corrective action

What's The Requirement?

Control of Purchases

- Meet MIL-Q-9858

  Responsibility. The contractor is responsible for assuring that all supplies and services procured from his suppliers (subcontractors and vendors) conform to the contract requirements

- SAMSO STD 73-5B

  Responsibility. The contractor shall establish a supplier quality assurance program in accordance with MIL-STD-1535 and this standard

- MIL-STD-1535A

  Purpose. The purpose of this standard is to establish the procedures for an effective quality assurance program for Government procurement involving subcontracts when MIL-Q-9858 or MIL-I-45208 and this standard are requirements of the prime contract

Focus on Selected Critical Elements

- Are we flowing down the proper requirements?
- Are we verifying that the assurance requirements are placed on purchase order?
- Are we measuring vendor performance adequately?
- Do we involve the subcontractor adequately in the corrective action loop?

Are We Flowing Down the Proper Requirements?

- Provide documentation in the form of procured material requirements document
- Stipulate for each class of item being procured or each unique part:
  - Specific requirements to be placed on the subcontractor
  - Government source inspection
  - Contractor source inspection
  - Data requirements
  - Certification and testing requirements
  - Packaging and shipping requirements
  - Other requirements

SAMPLE OF PROCURED MATERIAL REQUIREMENTS DOCUMENT

PROGRAM NAME	
Tally No.	
Rev	Date

PURCHASE MATERIAL REQUIREMENTS
FIGURE 1
Purchase Order--Quality Requirements Summary

TYPE OF CONTRACT/QUALITY SYSTEM REFERENCES - Check as Applicable

DOD/MIL-Q-9858, MIL-I-45208 ☐
NASA/NHB 5300.4 (IB, IC) ☐
NAVY/MIL-Q-21549 ☐
OTHER (SPECIFY) ☐

PART TYPE	ATTACHMENT Q REFERENCE														PACKAGING		SPECIAL QUALITY REQ'TS
	21A	21B	21E	33	36	37	19	20	22A	22B	25	27	28	38	SEC	SPEC	
																	EXAMPLES Tightened req'ts not violating specs/ Appl. Deviations or Waivers. Quality doc'n transmittal.

Are We Verifying That the Assurance Requirements Are Placed on Purchase Order?

Perform quality assurance review of procurement documentation to verify:

- Proper application of quality assurance requirements as delineated in purchase material requirements document
- Use of approved suppliers
- Application of proper requirements for Group I, Group II and Group III purchases

SAMPLE OF APPROVED SUPPLIERS LIST

JOINT APPROVED SUPPLIERS LIST 04/04/78

(SORTED BY VENDOR NAME)

FAMILY CODE	HONEYWELL PART NUMBER	CLASS CODE	SUPPLIER NAME AND ADDRESS	QUALITY LEVEL	APPROVAL SRT	APPROVAL DTE	APPROVAL METH	RES DTE	REMARKS
PROCES	QQ-N-290 CL 1 2	POS	BROWARD INDUSTRIAL PLATERS FL LADFL	PROCESS	F	711	SF	903	* ADD#1
PROCES	QQ-P-35 TY 1 2 3 4	POS	BROWARD INDUSTRIAL PLATERS FL LADFL	PROCESS	F	711	SF	903	* ADD#1
PROCES	QQ-P-416 TY 1 2	POS	BROWARD INDUSTRIAL PLATERS FL LADFL	PROCESS	F	711	SF	903	* ADD#1
PROCES	QQ-S-365 TY 1 2 3	POS	BROWARD INDUSTRIAL PLATERS FL LADFL	PROCESS	F	711	SF	903	* ADD#1
PROCES	MIL-M-13508	POS	BRYSON COATING LAB SAFETY HARBOR FL	PROCESS	F	612	SF	806	
PROCES	MIL-G-45204B	POS	CINCH-MONADNOCK CITY OF INDUCA	45208	MCR	707	SM	901	18300 E VALLEY BLVD
PROCES	FPS-18137 34018752	POS	COMPRESSIVE INDUSTRY FT LAUDERDALFL	PROCESS	F	607	SF	801	
PROCES	FPS-18137 E B WELD	POS	COMPRESSIVE INDUSTRY FT LAUDERDALFL	PROCESS	F	607	SF	801	
PROCES	MIL-I-6866	POS	CONAM INSPECTION INC MN	PROCESS	MNP	606	SM	712	1925 OAKCREST SUITE 11
PROCES	PC-13404-01B	POS	CONNOR SPRING&MFG MONTEREY PK CA	PROCESS	MNP	709	SM	903	ATTN; GARY SPANOS
PROCES	QQ-P-035B TYPE II	POS	CONNOR SPRING&MFG MONTEREY PK CA	PROCESS	MNP	709	SM	903	831 MONTEREY PASS RD
PROCES	MIL-A-8625 TYPE II	POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN@ V. ROSENBLUM
PROCES	MIL-C-26074	POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN V. ROSENBLUM
PROCES	MIL-C-5541 B	POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN V. ROSENBLUM
PROCES	MIL-T-10727 TYPE I	POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	1605 IGELHART AVE.
PROCES	PC-13331-01	POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN@ V. ROSENBLUM
		POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN V. ROSENBLUM
		POS	COOPERATIVE PLATING MN	PROCESS	MNP	703	SM	809	ATTN V. ROSENBLUM
		POS	CRAFTMAN PLAT & TINNING	PROCESS	MNP	705	SM	811	* ADD#1
		POS	DIXIE PLATING INC 3140 46 AVE N SFL	PROCESS	F	608	SF	802	
			INC 3140 46 AVE N SFL	PROCESS	F	608	SF	[illegible]	
			3140 46 AVE N SFL	PROCESS	F	[illegible]			
			46 AVE N SFL	[illegible]					
			AVE [illegible]						

Are We Measuring Vendor Performance Adequately?

An organized vendor rating system is required to give perspective on vendor/subcontractor performance.

Ratings should reflect:

- What has he done lately?
- What is his past year's performance?
- What is the cost of the material? Of rejections?

Vendor rating reflecting cost impact of nonconforming material is very useful.

Vendor Rating Examples:

- Lot acceptance percentage
- Lot acceptance percentage for latest month
- Lot acceptance percentage for last 12 months
- Parts acceptance percentage for last month
- Parts acceptance percentage for past 12 months
- Cost of material procured
- Cost of rejections - Actual $$ and cost impact (rejection cost per $1000 of procured material)

ELECTRICAL SUPPLIER QUALITY RATING REPORT

-PCB FLEX CABLES/PRINTED CB

FIRST LINE = MARCH
SECOND LINE = LAST 12 MONTHS

SOURCE CODE	VENDOR NAME	LOTS TOTAL	LOTS ACPT	LOTS %ACPT	PARTS TOTAL	PARTS ACPT	PARTS %ACPT	PROC. COST	IMPACT COST	C.I.
ANYCX01	APPLIED DIGITAL DATA SYS	0	0	0	0	0	0	0.	0.	0.
		2	2	100	2	2	100	680.00	0.	0.
BMADJ01	BOUDREAU CONSULTING	0	0	0	0	0	0	0.	0.	0.
		1	1	100	2	2	100	626.00	0.	0.
BMD2104	BARGALE INDUSTRIES	0	0	0	0	0	0	0.	0.	0.
		14	11	78	60	50	83	4074.26	330.00	81.0
CCAAV01	CIRTEL INC.	0	0	0	0	0	0	0.	0.	0.
		12	9	75	1753	891	50	28063.00	300.00	10.7
CCO0501	COLORADO CIRCUITS	0	0	0	0	0	0	0.	0.	0.
		1	1	100	2	2	100	586.24	0.	0.
CIA1301	COLLINS RADIO CO	1	0	0	36	0	0	1416.60	120.00	84.7
		16	9	56	556	248	44	18579.35	830.00	44.7
GFL0305	GENERAL COMPONENTS	2	2	100	19	19	100	1330.00	0.	0.
		2	2	100	19	19	100	1330.00	0.	0.
GFL0402	GENERAL COMPONENTS INC.	14	13	92	21	20	95	8780.00	120.00	13.7
		558	500	89	3079	2650	86	579108.74	6540.00	11.3
HMA0561	HONEYWELL INFO SYSTEMS	0	0	0	0	0	0	0.	0.	0.
		4	4	100	14	14	100	4697.00	0.	0.
		39	34	87	1860	1548	83	34180.40	556.00	16.3
		888	707	79	17106	9080	53	816911.14	30922.00	37.9

<u>Do We Involve the Subcontractor Adequately in the Corrective Action Loop?</u>

Communicate with subcontractors quality organization regarding nonconforming material

- Information to subcontractor regarding nature and quantity of nonconformances, requirements for response to customer and information on who he can contact in the contractors organization for details.

Honeywell

Attn: Quality Control Manager

Attachment: Supplier Nonconformance Report # 150

Dear Sir:

Material recently received at Honeywell Avionics Division was found by our Incoming Inspection Department to contain nonconforming characteristics. These nonconformances are defined on the attached Supplier Nonconformance Report.

No. 510

Honeywell Avionics Division
13350 U.S. Highway 19
St. Petersburg, Florida 33733
813/531-4611

SUPPLIER NONCONFORMANCE REPORT

To: P.O. #__________ Date________
Part #__________
Part Name__________
HI Lot #__________
Q.A. Eng_____/_____ Ext_____
Attn: Quality Control Manager Buyer__________
No. of Pieces In This Lot________

Specification	Sample/# Size/Def's	Nonconformance

This Supplier Nonconformance Report is to bring to your attention that Honeywell has received nonconforming material.

☐ Please use this as information to prevent future nonconforming shipments.

☐ You are requested to take corrective action and report back to Honeywell within 30 days the action taken to prevent recurrence.

1) White - Supplier 2) Canary - MQA Eng. 3) Pink - Buyer 4) G-Rod- CA Data Center
F2.PT-0347(676)

Conclusion

Mission assurance success is enhanced if we:

- Identify the proper quality requirements for the subcontractor
- Verify that these requirements are conveyed to the subcontractor
- Rate vendors on an organized basis for timely action
- Communicate fully with vendors for corrective action.

WORKSHOP SUMMARY

WORKSHOP SUMMARY

Subcontractor/Supplier Interface and Control

• **Problem No. 1**

Lack of definition and standardization of technical requirements and consistency of flow down to subcontractor level.

Recommended Solution:

Establish standardization board with the authority to publish internal direction.

Action Agency – SAMSO

• **Problem No. 2**

Lack of bidders due to economic conditions.

Recommended Solutions

- Recognize front end funding and add inducement to bidders to bid
- Tailor requirements when practical to fit small business and minority capabilities
- Recognize development funds for small business and minority business to develop technological capabilities.

Action Agency – SBA/SAMSO

• **Problem No. 3**

Technical requirements too detailed.

Recommended Solution

- Emphasize feasibility studies
- Emphasize performance type requirements
- Minimize "how to" specs.

Action Agency – SAMSO/DOD

• **Problem No. 4**

Lack of failure historical data.

Recommended Solution

Broader dissemination of failure data throughout industry and government.

Action Agency – SAMSO

• **Problem No. 5**

Too many audits.

Solution

Interchange among agencies and programs to minimize audit frequency and duration.

Action Agency – SAMSO/DOD/NASA

COMMENTS BY JEROME FISHEL, CTI, AS VIEWED BY A SECOND TIER SUBCONTRACTOR

1. Chain of Command:

When we request a deviation from our Customer, we are often told that they are reluctant to take it Upstairs because of the particular situation which may exist. Therefore, we are denied approval of our request without regard to its merit. I would suggest that some method be developed to allow us to go directly to higher authority in those special situations.

2. Small Management Company Briefings:

I believe SAMSO should acquaint the Managements of their small company team members with the full details and significance of the various programs. I came away from our meeting with a greater sense of the appreciation and importance of what we are doing.

3. Technical Expertise:

I strongly recommend that the SAMSO/Aero Space Technical Staff allow the subcontractor to produce the parts using methods and processes which they are trained and familiar with. It is necessary in many cases for a Manufacturer to be 'monitored' to insure that he complies with good practices. However, this is different than being directed in how he should do it.

4. It would be desirable if SAMSO/Aero Space would provide technical services such as: failure analysis, specification testing, etc. to the smaller subcontractors where necessary. This would be very helpful.

WORKSHOP F

DEVELOPMENT & CONTROL OF MICROELECTRONICS/HYBRIDS/LSI DEVICES FOR SPACE APPLICATION

Co-Chairmen

Dr. Jack Hilibrand, Staff Tech. Advisor
Gov't. Systems Div., Engineering
RCA Corporation

Mr. James J. Egan
Head, Components & Product
The Aerospace Corporation

AGENDA

Wednesday, April 26

0830-0840	Opening Remarks	Co-Chairmen
0840-0905	CMOS/SOS Reliability Status	Mr. Eugene M. Reiss, RCA
0905-0930	I^2L/LSI in Military Applications	Mr. Klaus K. Schuegraf, Northrop
0930-0955	Radiation Effects on LSI	Mr. James P. Raymond, Mission Research
0955-1020	Hi Rel Applications of Custom LSI	Mr. John D. Heightly, Sandia
1020-1045	Design Tools for Custom LSI	Mr. Jack Hilibrand, RCA
1045-1110	Testing Microprocessors	Mr. Lenward E. Holmess, HAC
1110-1135	Microprocessor Slash Sheet Development	Mr. W. Richard Scott, JPL
1135-1200	Memory Design and Testing for Hi Rel Applications	Dr. Joseph S. Bravman, Fairchild
1200-1215	Class S LSI Plans	Mr. Alan J. Carlan, Aerospace
1215-1315	Lunch	
1315-1340	Hybrid Microcircuits	Mr. Jerome Fishel, CTI
1340-1405	Hi Rel Hybrid Manufacturing Considerations	Mr. Ralph Redemske, Teledyne
1405-1430	Hybrid Chip Screening and Evaluation	Mr. John deJong, JPL
1430-1455	Class S Hybrid Circuit Committee	Mr. Donald L. Fresh, Aerospace
1455-1520	Implementing Commanders Policy for Supplier Surveillance	Mr. Warren Geller, LMSC
1520-1545	Coordinated Procurement for IUS	Mr. Wilber L. Barker, Boeing
1545-1600	Break	
1600-1715	Conclusions and Recommendations	Group Discussion
1715-1730	Summary	Co-Chairmen
1730	Adjournment	

CMOS/SOS
A LSI/VLSI TECHNOLOGY

Eugene M. Reiss
Mgr., MOS High Reliability Engineering
RCA Solid State Division

The benefits of CMOS are well known throughout the industry. As a result there has been dramatic growth in the number of CMOS functions, devices delivered and the number of vendors during the past six years. Coupling the CMOS technology to a sapphire substrate, CMOS/SOS, produces additional improvements in performance and cost for LSI/VLSI functions. These improvements are related to properties inherent in the silicon on sapphire structure, such as: a) low parasitic capacitance, b) high packing, c) density, d) good yield potential, e) resistance to transient effects. However, there are concerns which relate to a) high cost of starting wafers, b) reliability of a new technology, c) production capability and d) multiple sourcing.

Although the SOS technology has been in the laboratory for over 10 years, it is during the past two years that it has been converted to a production process. As a result, the cost of the sapphire substrate has been decreasing and additional major cost reductions are anticipated through the introduction of the ribbon process. As this occurs, the cost of the substrate in the finished wafer will also decrease and will not be a significant cost factor. During this same period of time, production capability was established and long term device stability at 125°C demonstrated. As a result RCA has committed all new CMOS LSI/VLSI designs to the SOS technology. The ability to produce SOS devices by multiple vendors has also been demonstrated. The recent RCA-Intel technology exchange agreement, will provide another major source of SOS products.

Although CMOS/SOS has these advantages:

- Low parasitic capacitance
- High packing density
- Reduced sensitivity to effect of pinholes
- No substrate warpage during diffusion
- Built-in resistance to transient radiation effects
- Military temperature range
- Wide operating voltage.

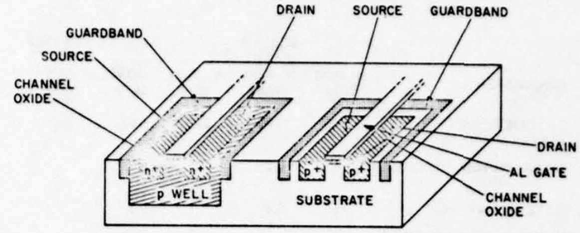
CMOS/SOS Advantages for LSI/VLSI

Lower parasitic capacitance results in greater speed and lower operating power

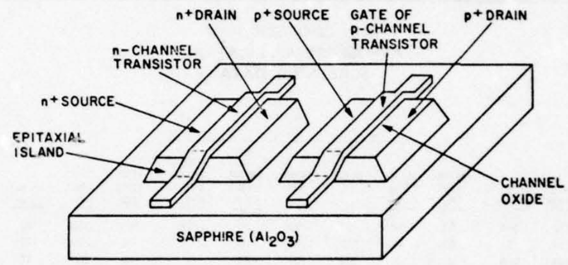
$$t = RC$$

$$P_{ac} = CV^2f$$

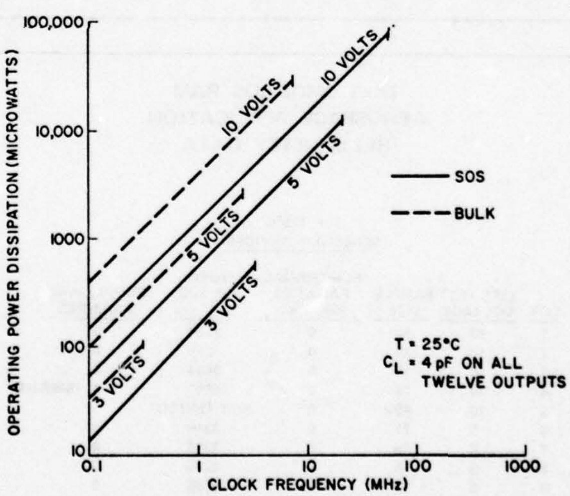
STRUCTURE OF BULK MOS TRANSISTORS



STRUCTURE OF SOS MOS TRANSISTORS



COMPARATIVE DISSIPATION
BULK CD4040 VS SOS CDS4040
(12 STAGE COUNTER)



CMOS/SOS Advantages for LSI/VLSI

- High packing density
- Guardbands not required
- Planar structure
- Capability for scaling

UPDATED MOS LSI TECHNOLOGY OVERVIEW

PARAMETER	H–MOS 1977	SCALED DOWN H–MOS 1980+	V–MOS 1977	SOS 1977	CDP1804 SOS 1978
LAYOUT DENSITY ($GATES/MM^2$)	170	200	220	150	242
SPEED POWER PRODUCT (PJ)	1	0.2	1	0.2	
GATE DELAY (ns)	1	0.4	1	0.5	
NUMBER OF THIN FILMS	2	2	3	3	
NUMBER OF IMPLANTS	3	3	3	2	

← From "Electronics" · · · August 18, 1977 · · · Page 99 →

1Kx1 CMOS/SOS RAM AEROSPACE APPLICATION SCREENING DATA

			125°C							
DATE CODE	GROSS NO. OF UNITS	INITIAL TEST (%)	168 HR. DYN. (%)	24 HR. S.I. (%)	24 HR. S. II (%)	240 HR. DYN I (%)	REBURN 240 HR. DYN. II (%)	TEMP. 125°C (%)	TEST −55°C (%)	X-RAY (%)
7738	394	53	94	97	99	85	99	100	100	95
7739	70	68	92	100	98	98	–	79	100	100
7741	189	65	71	100	100	99	–	100	100	98
7742	166	45	64	100	100	95	–	95	100	86
7743	180	59	66	99	100	97	–	98	100	100
7743	242	58	87	99	99	92	–	97	100	100
7746	366	77	89	99	99	96	–	100	100	100
7747	302	74	87	98	98	94	–	97	99	94
7751	1110	77	87	99	99	99	–	97	99	99
TOTAL	3019	67	85	99	99	95	99	97	99	98

1Kx1 CMOS/SOS RAM AEROSPACE APPLICATION RELIABILITY DATA

T = 125°C
SCREENED DEVICES

LOT	LIFE TEST VOLTAGE	SAMPLE SIZE	FUNCTIONAL FAILURES 1000 HRS.	TOTAL HOURS TESTED	FUNCTIONAL FAILURES
1	10	12	0	3624	0
2	10	19	0	3288	0
3	10	18	0	3624	0
4	10	14	0	5802	1 (5466 HR)
5	10	45	0	NOT TESTED	
6	5	21	0	3316	0
7	5	16	0	3316	0
8	5	8	0	3316	0
9	5	13	0	5730	0
10	5	77	0		
TOTAL		243	0		

TOTAL DEVICE HOURS 597,794
FUNCTIONAL FAILURES 1

FAILURE RATE, 60% CONFIDENCE

T = 125°C = 0.34%/1000 HRS.
T = 55°C = 0.0003%/1000 HRS.

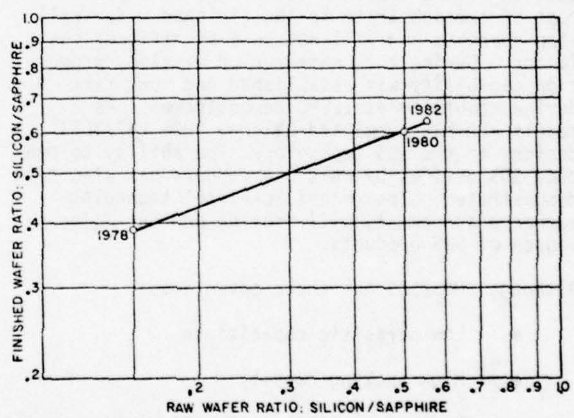
Concerns:

- High wafer costs
- Reliability of a new technology
- Production capability
- Multiple sources

CMOS/SOS Concerns

- High wafer costs
  - Sapphire finished wafer cost ratio to bulk silicon is less than two to one today and improving
  - Higher packing density gives 60 percent more dice on a sapphire wafer
  - Improved yields are expected to result in lower die cost than with bulk
  - As a result, all new LSI and VLSI CMOS designs at RCA are being implemented in SOS technology.

WAFER COSTS



CMOS/SOS Concerns

- Reliability of a new technology
  - Commercial product data base established
    - By end of 1977 over 150,000 net die per month
    - 0.0004 percent/1000 hrs, 55°C, 60 percent confidence
  - Screening data indicates product stability
  - High-reliability data base established.

INDUSTRY MOS LSI TECHNOLOGY OVERVIEW

FROM ELECTRONICS
APRIL 1, 1976
PAGE 76

TECHNOLOGY	PERFORMANCE: PROPAGATION DELAY (ns)	PERFORMANCE: POWER DELAY PRODUCT (PJ)	COST: DENSITY (DEVICES/MM²)	COST: DENSITY (GATES/MM²)	CHIP SIZE (MM²)
HIGH-THRESHOLD P-CHANNEL METAL GATE	80	450	150	50	7 x 7
P-CHANNEL SILICON GATE	30	145	270	90	6.5 x 6.5
N-CHANNEL SILICON GATE	15	45	285	95	6 x 6
N-CHANNEL SILICON GATE DEPLETION-LOAD	12	38	320	107	6 x 6
N-CHANNEL *DOUBLE POLYSILICON*	10	35	525	175	6 x 6
SILICON GATE C MOS	10	0.5	220	45	5.5 x 5.5
V MOS D MOS	5	20	600	225	–
SOS/C MOS	2 – 5	0.1	660	275	5 x 5
I^2L (DOUBLE LEVEL)	5 – 50	0.01 – 1	500	150	5.5

CMOS/SOS Concerns

- Multiple sources
  - NSA study demonstrated that 5 vendors had capability to process an SOS test chip with same resultant test data
  - Hewlett Packard
  - INTEL agreement.

Conclusions

1. The CMOS/SOS technology has made significant advances during the past two years and it is in production status at RCA and can be qualified for applications in space.
2. CMOS/SOS is the leading technology for VLSI functions as a result of its outstanding speed power product and high packing density.
3. CMOS/SOS devices have demonstrated long term stability at 125°C.
4. Mask compatible second sourcing is available.
5. RCA is fully committed to supplying space qualified CMOS/SOS parts.

Recommendations

The aerospace industry should be making more use of CMOS/SOS technology.

I^2L-LSI IN MILITARY AND SPACE APPLICATIONS

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SUMMARY

The military application of LSI circuitry places increasing demands on the present technologies. A major requirement for future systems implemented with digital random logic is to increase the level of integration on a single LSI chip such that the component count be increased from a few thousand (i.e., LSI) to over ten thousand (i.e., VLSI, Very Large Scale Integration). Past performance of military systems that utilize MSI and LSI electronic components exhibit improved reliability and in many cases lower costs for initial procurement as well as for maintenance. These advantages will be extended by the application of VLSI for custom random logic for military applications. However, this increase in integration level should be achieved without a substantial decrease in the ability of the device to operate over the full military temperature range or in nuclear radiation environments.

Integrated Injection Logic (I^2L) is a high packing density technology that utilizes the structural merging of an npn transistor with a pnp current source to provide moderate performance at very low voltage operation. Thus, power-delay products of 0.5×10^{-12} J are realistic for gates using a set of "relaxed" minimum geometries.

I^2L LSI technology is well suited to a wide range of military digital logic applications. These applications frequently demand survival in nuclear radiation environments. The low power and high packging advantages of I^2L need not be "traded-off" for improved radiation hardness levels. Design and performance parameters for an I^2L technology for military applications are:

1. Logic Gate Performance Parameters
   - Operational Temperature Range: $-55°$ to $125°C$
   - Minimum Propagation Delay: 5-10 ns/gate
   - Power Consumption at Minimum Delay: 0.1-0.3 mW/gate
   - Logic Gate Packing Density: 250 - 500 gates/mm^2
2. Radiation Failure Levels
   - Neutron Fluence: $\leq 5 \times 10^{13}$ n/cm^2
   - Total Ionizing Dose: 5×10^6 rad(Si)
   - Ionizing Dose Rate: 5×10^9 rad(Si)/sec

These performance parameters are consistent with realistic electronic systems requirements of the 1980's. They can support the majority of hardware requirements that the military presently implement with small-scale and medium-scale TTL devices. However, the use of large scale I^2L devices has the advantage of lower power consumption and higher packing densities than TTL. Hence, a radiation hardness I^2L technology offers military electronics systems suppliers a means to keep pace with the demand for increasing functional complexity without sacrificing radiation hardness.

Trend in Electronic Hardware for Military and Space Applications

- Increasing use of digital techniques
  - Data transmission: secure voice, AJ data links
  - Digital signal processing: video, radar, BW compression
  - Avionics/spaceborne computers/controllers
- Increasing sophistication made possible by low cost microprocessor chips, low cost memory
- Demand for military qualified LSI technology
  - 10^3 - 10^4 functions per LSI chip at moderate cost
  - Medium speed at low power
  - Full MIL temperature range
  - Radiation hardened

What LSI Technology to Choose?

Problem: No single LSI technology exists to satisfy the majority of military/space requirements

- Low power at medium speed: 100 μW/gate at 25 MHz
- MIL temperature range: -55 .... +125°C
- Radiation hardened: Total dose $\gamma > 10^6$ Rads

  Neutron $\phi > 10^{13}$ n/cm^2

  Transient upset $\dot{\gamma} > 10^9$ Rads/sec
- Moderate cost: ~1¢ per gate
- Multiple sourcing
- High reliability

I^2L/LSI Technology is Ideal for Complex Logic Chips

- Adequate speed (15 to 20 MHz)
- Low power (100 μW/gate)
- High packing density (5000 gates/chip)

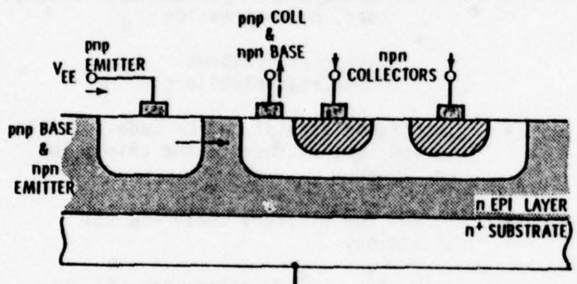
- Full military temperature range (-55 to +125^{o}C)
- Simplified fabrication
- Good radiation hardness
- Growth potential

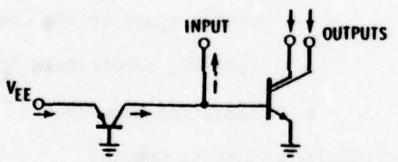
  Speed (30 MHz)

  Density ($\geq$10,000 gates/chip)
- Chip compatibility

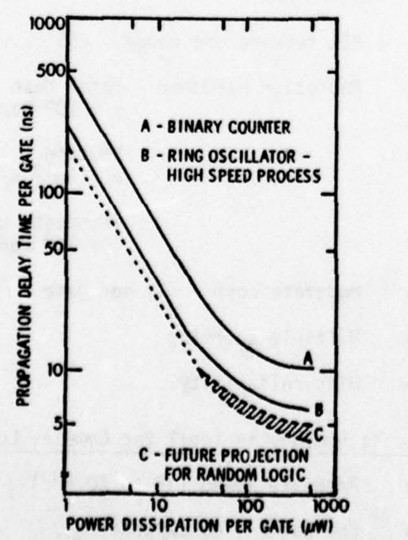
  Analog and digital functions

  High speed ECL and medium speed I^2L





BASIC I^2L LOGIC GATE



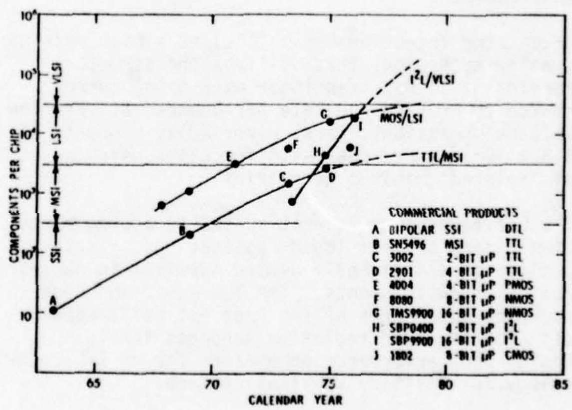
MEASURED AND ESTIMATED DELAY-POWER PERFORMANCE FOR I^2L GATES

COMPARISON OF LSI POWER CONSUMPTION

TECHNOLOGY	POWER FOR 10^3 GATES (WATT)
I^2L	0.1 - 0.2
LSTTL	2
ECL	5
SOS/CMOS	0.4

ASSUMPTIONS: (1) 10 MHz OPERATION

(2) FOR SOS/CMOS, 25% OF ALL GATES OPERATE AT 10 MHz



NUMBER OF COMPONENTS PER CHIP VS TIME

LSI RADIATION PERFORMANCE COMPARISON

TECHNOLOGY	NEUTRONS n/cm^2	TOTAL DOSE Rad(Si)	DOSE RATE Rad(Si)/Sec
I^2L (PRESENT)	5×10^{13}	3×10^{6}	3×10^{9}
I^2L (ADVANCED)	1×10^{14}	5×10^{6}	5×10^{9}
TTL	1×10^{14}	$1 \times 10^{5} - 1 \times 10^{7}$	$1 \times 10^{8} - 1 \times 10^{9}$
ECL	1×10^{15}	$1 \times 10^{7} - 1 \times 10^{8}$	$1 \times 10^{8} - 1 \times 10^{9}$
SOS/CMOS	1×10^{15}	$1 \times 10^{5} - 1 \times 10^{6}$	$2 \times 10^{10} - 1 \times 10^{11}$

PERFORMANCE CRITERIA	I^2L PERFORMANCE	REMARKS
FULL MIL TEMPERATURE RANGE	• MAXIMUM SPEED INSENSITIVE TO TEMPERATURES OVER -55°C to +125°C	• MAXIMUM SPEED DEPENDS ON CURRENT AVAILABLE TO SUPPLY npn BASE CHARGE – BOTH DEPEND ON TEMPERATURE THROUGH n_i – HENCE TEMPERATURE EFFECTS CANCEL OUT
SPEED-POWER TRADEOFFS	• SPEED FOR I^2L IS VARIABLE WITH INJECTOR CURRENT OVER 4 DECADES	• POWER FOR VARIOUS COMPONENTS OF A SUBSYSTEM CAN BE ADJUSTED TO ACHIEVE REQUIRED SPEED • SINGLE GENERIC DEVICE TYPE (e.g., MICRO-PROCESSOR, RAM, GATE ARRAY, etc.) CAN BE DESIGNED FOR VARIETY OF APPLICATIONS
INPUT/OUTPUT COMPATIBILITY	• I^2L, A BIPOLAR TECHNOLOGY, OFFERS TTL AND ECL COMPATIBILITY	• THE HIGH CURRENT GAIN OF BIPOLAR TRANSISTORS ALLOWS "SCALING-UP" OF CURRENTS WITHOUT EXCESSIVE TIME DELAY OVER SEVERAL STAGES AS IN MOS/LSI
RADIATION HARDENING	• I^2L OFFERS THE POTENTIAL FOR GOOD HARDNESS AT INCREASED LOGIC SPEEDS	• THE PACKING DENSITY AND COST BENEFITS OF COMMERCIAL I^2L WILL NOT BE LOST FOR HARDENED I^2L

SUMMARY OF I^2L PERFORMANCE CHARACTERISTICS

I^2L RELIABILITY

PERFORMANCE ADVANTAGES: LOW POWER TECHNOLOGY - LOW CHIP TEMPERATURE, LOW CURRENT DENSITIES

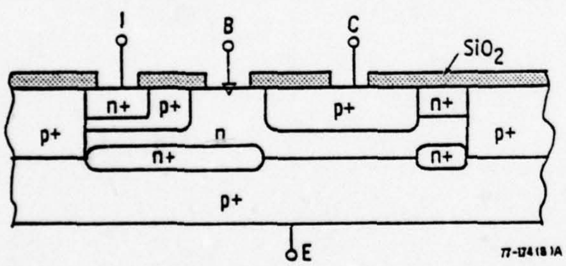
LOW VOLTAGE OPERATION (< 1 V) - REDUCED ELECTROLYTIC EFFECTS

HIGH SURFACE CONCENTRATIONS - NO SURFACE INVERSION

TEST RESULTS:

ELECTROLYSIS:	>1000 HR. OPERATION IN SALT WATER
BIAS TEMPERATURE:	< 1.0 FIT AT 60°C
BIAS HUMIDITY: 25°C/50% RH	< 10 FITS OVER 40 YEAR LIFE
GAIN DEGRADATION:	< 10% AT 250...275°C EQUIVALENT TO 40 YEARS END-OF-LIFE DEGRADATION
ACCUMULATED DEVICE HOURS:	60×10^6 HRS. WITH NO REPORTED CHIP FAILURES

SOURCE: F.W. HEWLETT & R.A. PEDERSEN
14th PROC. REL. PHYS. 1976



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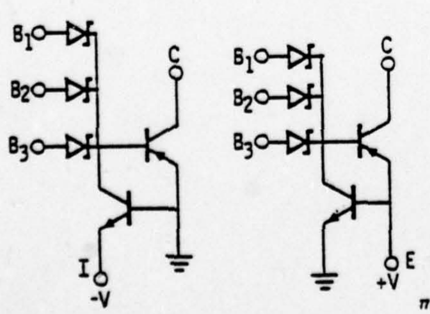

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ADVANCED I^2L TECHNOLOGY: SCHOTTKY BASE I^2L

BENEFITS OF SCHOTTKY BASE I^2L FOR RANDOM LOGIC

- SIMPLIFIED LSI DESIGN AND LAYOUT
  - MULTIPLE GATE INPUTS AND OUTPUTS
  - REDUCED INTERCONNECTION COMPLEXITY
  - IMPROVED ISOLATION BETWEEN CELLS
  - GROWTH POTENTIAL FOR VLSI
- GOOD MINIMUM DELAY TIME <5 nsec
- FAVORABLE DELAY-POWER PRODUCT <0.5 pJ
- EXCELLENT RADIATION TOLERANCE $\Phi > 5 \times 10^{13}$ n/cm^2
  $\gamma > 5 \times 10^6$ Rads
  $\dot{\gamma} > 5 \times 10^9$ Rads/sec
- IMPROVED INPUT/OUTPUT INTERFACE CAPABILITY
  - TTL COMPATIBLE
  - TRI-STATE CAPABILITY

Conclusions

- I^2L is a viable LSI technology for military and space applications
- I^2L can meet temperature and radiation hardness requirements for space applications
- I^2L gate arrays will permit low volume/fast turn-around LSI implementations
- I^2L failure rates of less than 10 fits under normal stress are predicted
- Advanced I^2L has growth potential for VLSI ($\geq$50 MHz, $\geq 10^4$ gates per chip)

Recommendations

- Provide incentives for LSI/VLSI utilization in space systems
- Encourage set-up of systems-oriented custom LSI centers with qualified low volume fabrication facilities
- Encourage development of LSI technologies with high degree of fabrication commonality to assure second sourcing
- Establish procurement policies to guarantee lifecycle support for LSI parts
- Develop user-oriented LSI performance- and reliability-test procedures and specifications.

RADIATION EFFECTS IN LSI

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ABSTRACT

Two critical aspects of radiation effects on LSI arrays are presented for discussion: 1) the relative evolution of high performance LSI arrays and radiation hardness, and 2) unique experimental and analytical techniques necessary for array evaluation and hardness assurance.

Radiation susceptibilities of the major LSI technologies (n-MOS, CMOS/SOS, and I^2L) are briefly reviewed. In each case the overall radiation susceptibility increases with increasing array complexity, decreasing logic cell energy, and decreasing the design margin of critical internal parameters.

The nature of radiation effects imposes unique test requirements on LSI arrays. The basic requirement is for a comprehensive evaluation of array performance, particularly for arrays designed without consideration of radiation effects. Any logic cell or sub-circuit can lead to array failure. A more difficult requirement is the definition of a set of test vectors to establish worst-case bias during radiation. For MOS arrays the electrical bias during exposure is a first-order effect in determining the total-dose failure level. For any digital array, the logic upset level is a strong function of the logic state during pulsed ionizing radiation exposure. In each case a large number of bias conditions can be defined and techniques must be developed to identify the minimum set of test vectors sufficient to reveal the worst-case. Short-term annealing effects, critical in some applications, impose a time urgency on electrical performance characterization following radiation exposure.

Efforts in the development of diagnostic/test support techniques also include the use of laser excitation, test elements and coupons, and considerations in overall evaluation of parameter margin from non-destructive techniques. It is not clear that these efforts are capable of either cathing the state-of-the-art in LSI technology, or keeping pace with its evolution.

	S/C TTL	ECL	I^2L	nMOS	CMOS	CMOS/SOS
Cell Density	0	-	+ +	+ +	0	+
Switching Speed	+	+ +	0	0	-	+ +
Static Power Dissipation	-	- -	+	–	+ +	+ +
Dynamic Power Dissipation	+	+	+ +	+	0	+
Speed-Power Product	0	0	+ +	+	0	+ +
Output Drive Capability	+	+	0	0	-	- -
Noise Immunity	+	0	- -	0	+ +	+ +
Temperature Range	+	+	+	-	0	-
Neutron Damage	0	+ +	-	+	+	+ +
Long-Term Ionization Damage	+	+ +	+	- -	-	- -
Transient Logic Upset Level	0	0	+	0	+	+ +

+ + superior, + good, 0 average, - below average, - - weak

Subjective Comparison of LSI Technologies

LIMITING RADIATION EFFECTS

N-MOS/LSI [1,2]

TOTAL IONIZING DOSE: 10^3 - 10^4 RADS(SI)

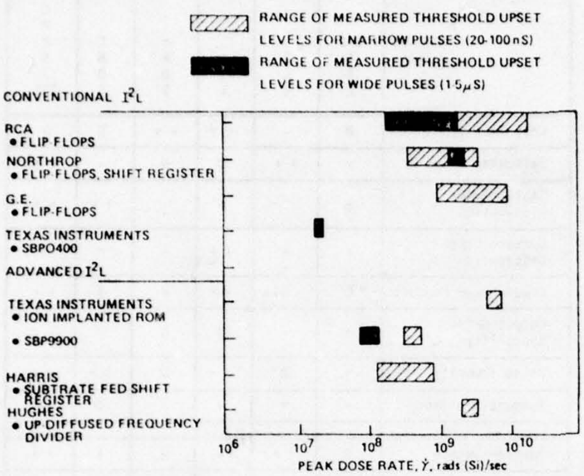
CMOS/SOS/LSI [3]

TOTAL IONIZING DOSE: 10^4 - 10^5 RADS(SI)

I^2L [4]

NEUTRON FLUENCE: 10^{13} - 10^{14} N/CM^2 (1 MEV EQUIV.)

(1) MYERS, NS-23, No. 6, PP. 1732-1737; DEC., 1976.
(2) MYERS, NS-24, No. 6, PP. 2169-2172; DEC., 1977.
(3) LEE, ET. AL., NS-24, No. 6, PP. 2205-2209; DEC., 1977.
(4) RAYMOND AND PEASE, NS-24, No. 6, PP.2327-2335; DEC., 1977.



Summary of Integrated Injection Logic Transient Photoresponse.

Unique LSI Testing Considerations

- Complete characterization

  New pattern sensitivities

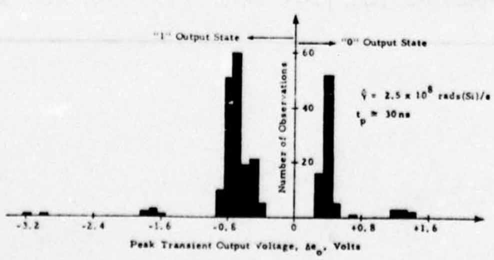
  "Random" critical cell failure

- Dependence on electrical bias during radiation exposure: long-term ionization effects
- Dependence on electrical bias during radiation exposure: power supply photocurrent/radiation-induced latch-up
- Short-term annealing effects

  Time urgency of post-irradiation performance characterization

- Dependence on observable logic states during radiation exposure.

2 x 4-BIT MULTIPLIER STATISTICAL TRANSIENT OUTPUT PHOTORESPONSE.



OBSERVATION OF TRANSIENT OUTPUT PHOTORESPONSE FOR VARIED INPUT CONDITIONS DEFINING THE SAME STATE ON A GIVEN OUTPUT TERMINAL. CONSTANT RADIATION EXPOSURE.

Developing Diagnostic/Test Support Techniques

- Pattern generation for transient radiation tests
- Test elements, coupons, wafers
- Laser excitation as photoresponse diagnostic
- Hardness assurance techniques — critical tolerance factor.

Recommendations

1) SAMSO/DoD involvement in VLSI evolution including n-MOS

   CCD

   CMOS/SOS

   Digital I^2L

   Combined bipolar analog/digital I^2L

2) Develop analytical methodologies in support of experimental evaluation of radiation susceptibility
   - Worst-case electrical bias
   - Worst-case logic state
3) Develop experimental methodologies in support of manufacturer and user hardness assurance
   - Test elements
   - Diagnostic techniques
   - Non-destructive margin evaluations
4) Require implementation and evaluation of test and analysis techniques on hardened arrays under development (i.e., practice).

HIGH RELIABILITY APPLICATIONS OF CUSTOM LSI

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The primary driving forces for the use of custom LSI in systems are size, reliability, reduced power dissipation, and cost. Applications requiring very high reliability have significant attributes that can dilute the advantages of custom LSI. It is important to recognize these attributes and minimize their effect. Some of the most important of these attributes are:

- Production volume is typically small.
- Design costs are high.
- Adequate testing is difficult to develop.
- It is difficult to establish confidence in the reliability of a design because of small production volume.

The net results of these attributes is that it is very difficult to interest any supplier in developing custom LSI circuits except at prohibitive prices. The primary reason for this is that one of the LSI suppliers most valuable resources is his design and engineering talent and he must get a high return on every investment of this resource.

The approach that Sandia Laboratories has taken to the development of custom LSI in order to minimize the effect of the above attributes has the following critical elements:

- All design is done in-house through mask generation.
- Standard, well characterized, building block cells are used in the design.
- Heavy use of computer aids is made throughout the design to minimize cost and maximize confidence in the design.
- Prototype devices are produced in an in-house processing facility using a process available at several production suppliers in the IC industry.

The use of standard cells in this approach is critical to achieving confidence in the reliability of an LSI design when the production quantities are very small. The cells are thoroughly analyzed, characterized, and the reliability assessed before they are used.

By doing the design and prototype production in-house, the development costs are kept reasonably low making the use of custom LSI in exploratory systems viable. In addition, the knowledge obtained from doing the development in-house is invaluable since reliability is treated as a critical requirement during development. It is not always possible to have the same emphasis in the very cost sensitive atmosphere at IC suppliers.

<u>Reliability Advantages of Custom LSI</u>

- Fewer interconnects, packages, and wire bonds
- Less power dissipation and heat
- Better inherent wafer fabrication process control required for LSI

<u>Potential Reliability Disadvantages of Custom LSI</u>

- Difficult to test adequately
- Difficult to apply stress to all devices
- Small production volume – little "learning" possible
- Die visual is difficult to perform

<u>Test Sequence Generation – Present Capability</u>

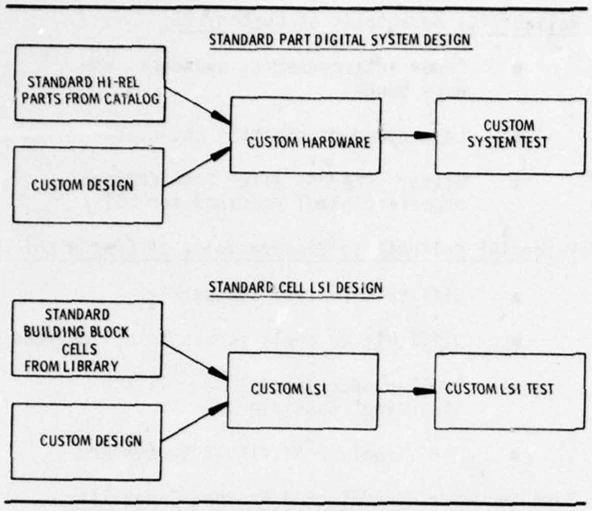
1) Manual test vector generation
2) Verification by simulation
3) States applied and gate activity statistics
4) Selectable fault options

<u>Test Sequence Generation – Future Capability</u>

1) Automatic and interactive test vector generation
2) Complete circuit exercising
3) Irredundant dominant set of faults
4) Controllability/observability measures for each node
5) Stuck fault coverage using parallel simulation
6) Functional level modeling
7) Circuit layout and physical defects
8) Fault dictionary

<u>Primary Wafer-Related MOS Defects and Screens</u>

Defect	Screen
Oxide contamination	High temperature – bias stress
	Static
	Dynamic
Oxide pin holes	High voltage stress – dynamic
Metallization	Sem wafer certification



Standard Cell Library

- Circuit designed with extensive analysis
- Layout complete with extensive checking for design rule violations
- Test chip fabricated and each cell characterized and reliability assessment performed
- Cell certified for inclusion in library
- Computer generated layout using cells from library to assure adherence to design rules and interconnect
- Analysis performed on critical paths using layout parameters

Advantages of Leadless Hermetic Packages

- Size
- No leads to corrode, crack, etc.
- Better temperature cycling characteristics when on thick film substrates
- Rugged

DESIGN TOOLS FOR CUSTOM LSI

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Key Words: Custom LSI, Circuit Design, Design Tools, CMOS LSI

Abstract

The development of reliable and cost effective Custom LSI Arrays has been made possible by the use of highly disciplined design procedures along with computer-aided design tools.

Introduction

The use of custom LSI parts involves the replacement of off-the-shelf SSI and MSI digital parts by a smaller number of more complex devices especially designed for the application (Figures 1 and 2). The conversion to custom LSI significantly reduces the number of parts and pins, and the number and complexity of PC boards so that there is a significant increase in reliability and a significant reduction in system fabrication cost. In addition, moving more of the interconnection network onto the chip improves system performance. Also, the reduced size and weight, and greater ease of shielding against radiation are significant advantages for space applications. Finally the use of subsystem scale logic elements permits easier diagnosis and part replacement. It is the use of custom LSI parts in watches, calculators, games, instruments, etc., which has transformed the American electronics scene.

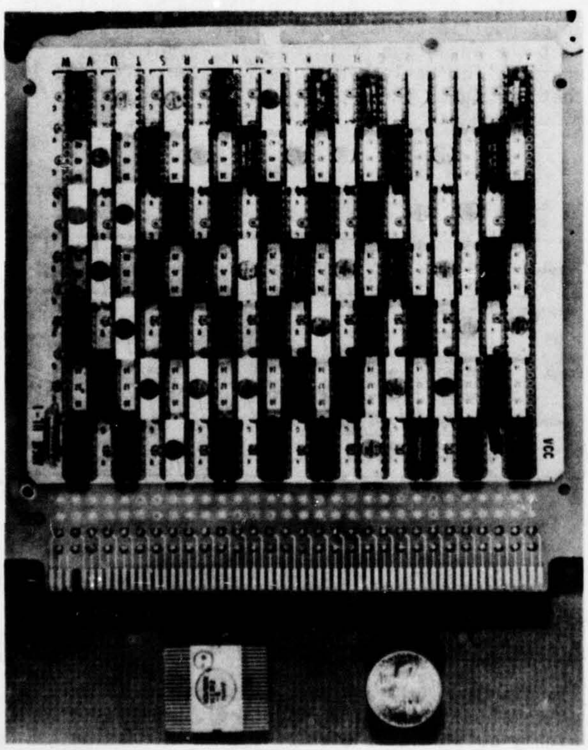


Figure 1. Comparison of LSI Device to the SSI Breadboard (Front)

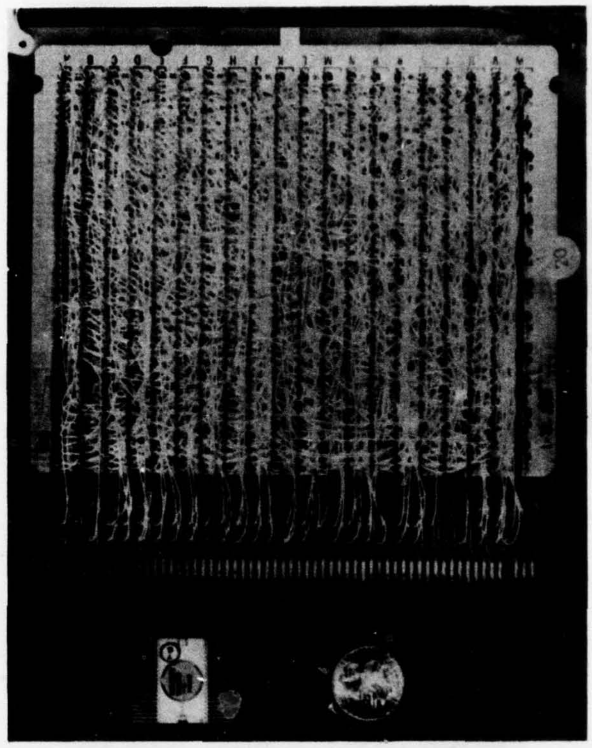


Figure 2. Comparison of LSI Device to the SSI Breadboard (Back)

Optimally designed digital systems of the future are likely to consist of microprocessor and memory devices surrounded by a small number of complex custom LSI parts which specialize the specific function being performed. This discussion will be focussed on complementary MOS technology which is well suited to such use by the low power dissipation per gate and the ease of design implementation.

There are three classes of custom LSI designs. The most familiar is the carefully "hand-crafted" design where an experienced semiconductor circuit designer converts a complex logic design into a layout of individual transistors which are tightly packed on the chip. Here is an example of a microprocessor, RCA's CDP 1802, (Figure 3) which was designed that way. A second approach is to design an array of individual identical transistors and to provide pathways by which this array can be customized using only the metal interconnect level (Figure 4). This is the Universal Array approach. Finally, a third approach is to design a library of multitransistor "standard cells" which perform each of the necessary elementary logic functions (Figure 5). A computer program is used to place the cells and route the interconnection network in an optimum way. These latter two approaches are the central topics of this paper.

Hand-Crafted Custom LSI

The basic problems with the hand-crafted approach are the cost of this procedure for a complex LSI chip and the numerous opportunities for minor, but fatal errors to creep into the layout. Hand-crafting results in the densest layouts and is widely used for memories where the primary focus

Figure 3. CDP 1802 CMOS Microprocessor; 5500 Devices; 7.6 Square Mils/Device

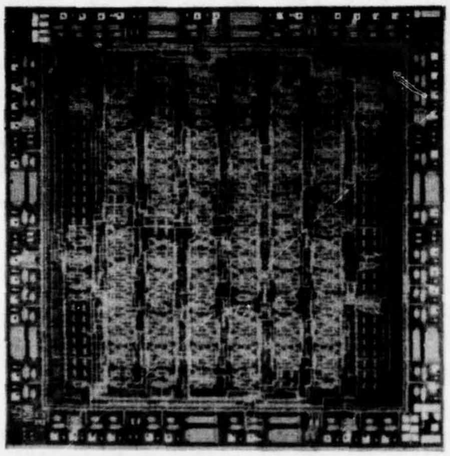


Figure 4. Universal Array Synch Generator Chip

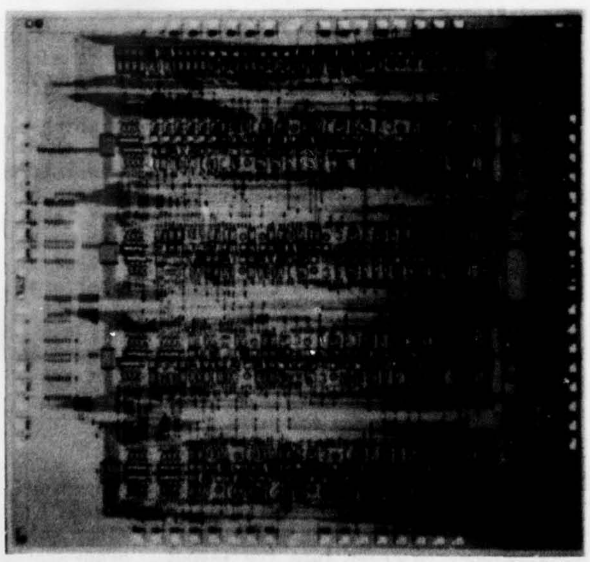


Figure 5. Standard Cell Arithmetic Logic Unit

is on absolute minimization of the size of the memory cell which is then replicated four, sixteen, or sixty-five thousand times. The designer's effort to save a square micron of cell area is well repaid in terms of a smaller chip and improved yield giving more net good chips per wafer, the ultimate measure of cost in the microelectronics world. The CMOS microprocessor uses seven square mil/device and RCA's 1024 bit CMOS static RAM uses three square mils/device. These are benchmarks for the hand-crafted design approach.

Universal Array Custom LSI

The Universal Array approach is at the other extreme in minimizing design costs while accepting significantly poorer packing density. Families of Universal Arrays (Figure 6) are available in each of the CMOS logic technologies. The device density is half an order of magnitude poorer than in the handcrafted design. The most complex phase of custom LSI design using the Universal Array, is the interconnection of the devices. This step is simplified by the use of predesigned appliques for each of the commonly used logic functions in which the size of the logic function is minimized (Figure 7). These appliques can be applied to a 500 scale mylar film version of the Universal Array and the interconnection pattern can then be laid out by hand. The interconnection matrix is then digitized and fed into a computer which generates a magnetic tape to drive a pattern generator and create the metallization mask level. Since wafers can be stockpiled fully metallized at the end of the wafer fabrication line, it is possible to get finished devices within a few weeks after the interconnection pattern is defined. Similarly, logic errors can be corrected and improvements in the system design can be implemented by relatively quick modifications of the single mask level. In fact the advantage of using a Universal Array approach for early system design stems from the low cost and quick turnaround possible when making minor changes.

TECHNOLOGY	TYPE NO.	ARRAY SIZE MILS	TOTAL NUMBER OF GATES	DEVICE DENSITY (SQ. MILS PER TRANSISTOR)	MAX. NO. OF PINS
METAL GATE	TCC 040	188 x 189	168	52.8	40
CMOS	TCC 061	229 x 232	276	48.1	48
C^2L CMOS	TCC 220	156 x 155	168	35.9	40
	TCC 221	186 x 188	276	31.6	48
	TCC 222	216 x 220	410	28.9	48
	TCC 223	246 x 252	576	26.9	64
SOS CMOS	TCS 090	145 x 145	182	28.8	40
	TCS 091	175 x 175	300	25.5	48
	TCS 092	205 x 205	452	23.2	64
	TCS 093	235 x 235	632	21.8	64

Figure 6. Universal Array Families

Standard Cell Custom LSI

The Standard Cell approach, also called APAR (Automatic Placement And Routing), provides a more highly automated scheme for custom LSI design. A library of thirty to fifty logic elements (Figure 8) is created, each of which is of constant

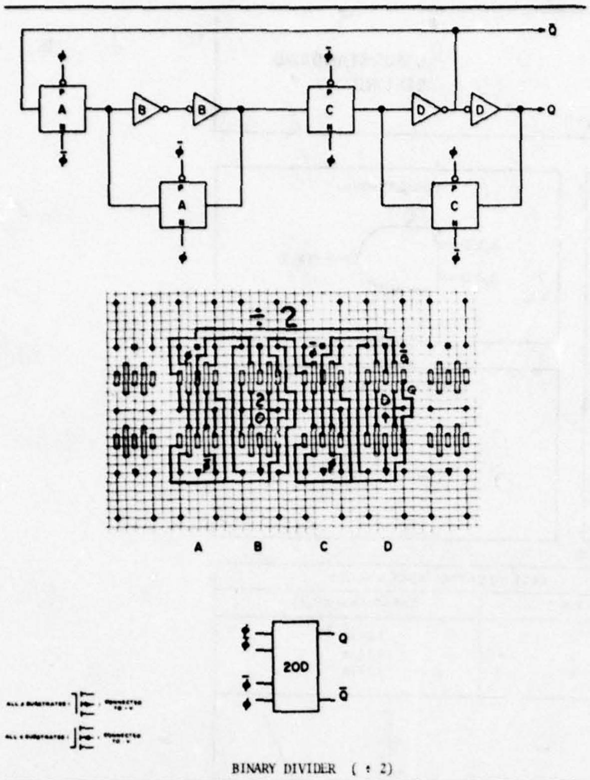


Figure 7. Binary Divider Logic Cell Applique

height and obeys specific rules on where the power and ground leads are tapped and where the signal inputs and outputs are available. These cells are laid out by experts to meet the design rules of the technology being used while offering minimum size and good performance. Interior devices inside the cell can be minimized in size while those which interface with the interconnection network are sized to drive on-chip wiring loads and those which drive the output pins of the device are made still larger to drive the board wiring. The cell layouts are then stored in computer memory. Computer programs have been developed which take the interconnection net list and optimally place the cells and route the interconnection wiring. The design engineer, who need not be expert in semiconductor design, examines a checkplot (Figure 9) of the layout which he can then modify slightly, if he wishes, to improve the packing density.

Which Approach to Use

These three approaches to custom LSI cover the spectrum of customer requirements (Figure 10). For low volume systems of five hundred gate complexity or less, the Universal Array is a cost effective approach. For high volume systems where getting to the absolute minimum chip size is important, handcrafted arrays are used. In the large middle area, standard cell approaches are most cost effective and this is the technique used most widely in the RCA Government Systems activities.

Design Disciplines for Custom LSI

Let's get some perspective on the design disciplines for reliable custom LSI. Military equipment designers are not generally semiconductor experts. They need access to an LSI design approach which will not only be cost effective (by minimizing front-end costs) but one which will not require them to learn the complexities of each new semiconductor technology as it comes along, and one which provides a high degree of assurance that the design cycle will be timely and the resulting chip will be reliable. The design cycle (Figure 11) involves interaction between the RCA system activities and the RCA Solid State Technology Center where the semiconductor masking, wafer fabrication, and parts assembly and test are implemented.

The Solid State Technology Center, a central corporate facility (Figure 12) was established seven years ago to provide a pilot line for advanced technologies where small quantities of mil-spec qualifiable parts could be gotten on a cost effective, quick-turnaround basis. The standard cell library (Figure 13) is reviewed by a corporate group for conformance to the design rules. Each cell is incorporated into a test vehicle chip (Figure 14) in which it can be individually burned-in and life tested. When this process is complete, the standard cell library is approved for use in high reliability applications and the cells are secured against all unauthorized changes. A similar procedure is used to formally adopt the Universal Array for high reliability applications. The cells and UA elements are characterized and User Manuals are issued to enable designers to access these tools. These procedures ensure that the basic building blocks for custom LSI designs are well understood and reliable so that equipment designers can use them with confidence.

Conclusions

RCA has organized to make Custom LSI technology available for a variety of systems applications because of our belief that the use of custom CMOS LSI parts (along with the microprocessors and memories) is the most reliable and cost-effective way to implement space systems.

Recommendations

In order to make the use of custom LSI parts practical: (1) Special attention is needed to provide for custom LSI part design early in the prototype and testing phase of programs so that the life cycle cost benefits from the use of LSI parts can be achieved during the production phase of the program. (2) Custom LSI parts should be qualified on a family basis through testing of standard cell libraries and Universal Array Vehicles rather than by fully qualifying each custom part individually.

Biography

Mailing Address:

Dr. Jack Hilibrand
RCA - Government Systems Division
Cherry Hill Offices 206-1
Camden, N.J. 08101

Jack Hilibrand joined RCA Laboratories in 1956 after receiving a Doctorate in Electrical Engineering from MIT. He was involved with the development of various semiconductor devices until 1961, when he joined what is now the Solid State Division and played a key role in developing the RCA COS/MOS

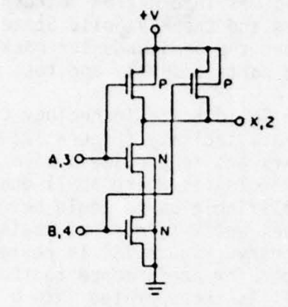
TWO–INPUT NAND

4 Devices
3 Pads

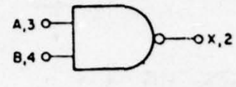
Cell Width 5.8 mils

C-MOS STANDARD
CELL NO. 1220

SCHEMATIC



LOGIC SYMBOL



LOGIC EQUATION

$X = \overline{A \cdot B}$

TRUTH/TABLE

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

CELL I/O CAPACITANCE VALUES

PIN	CAPACITANCE (pF)
2	1.04 pf
3	1.17 pf
4	1.17 pf

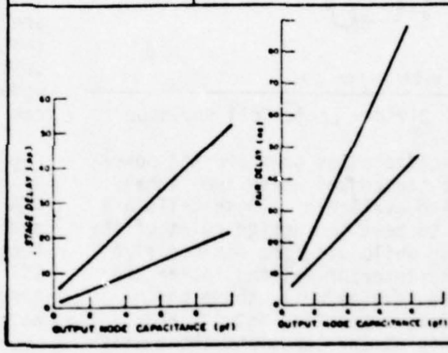


Figure 8. Standard Cell Data Sheet

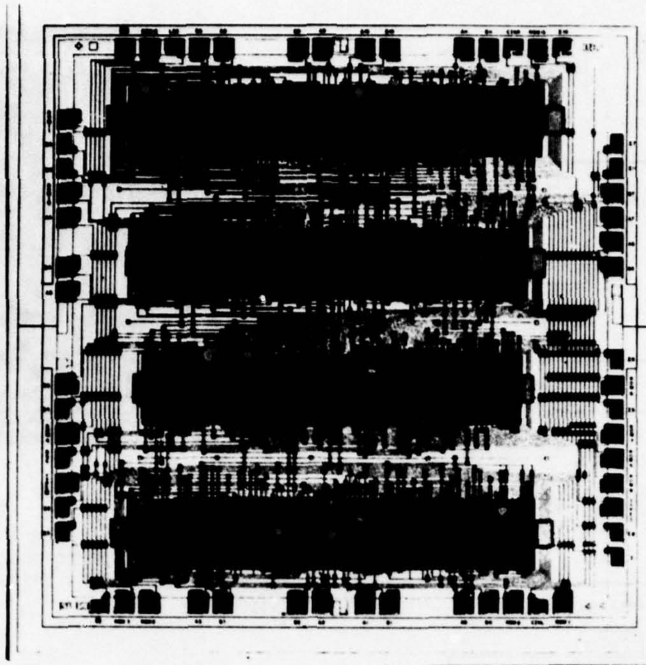


Figure 9. Checkplot of a Standard Cell Array

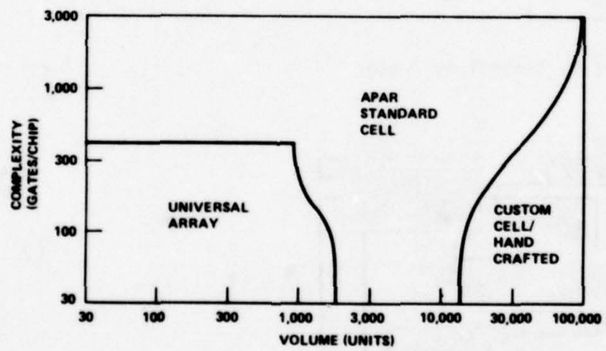


Figure 10. Design Tools — When to Use Them

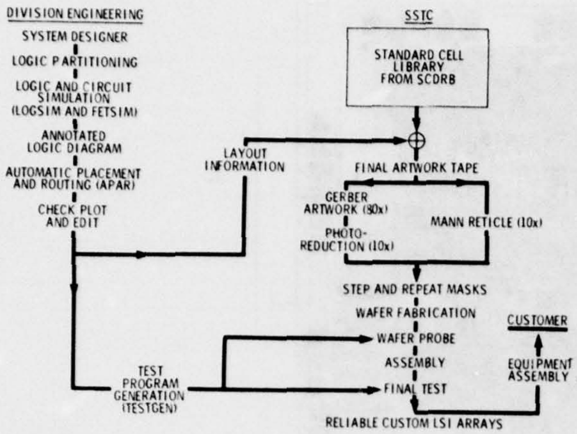


Figure 11. Design and Fabrication of Standard Cell Custom LSI Arrays

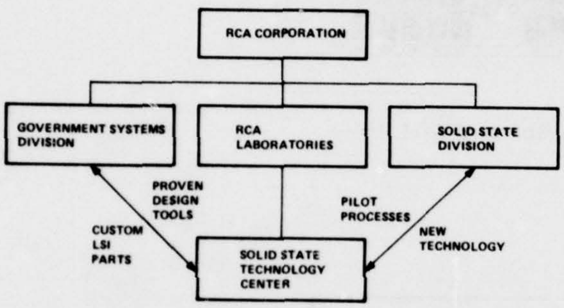


Figure 12. RCA Solid State Technology Center

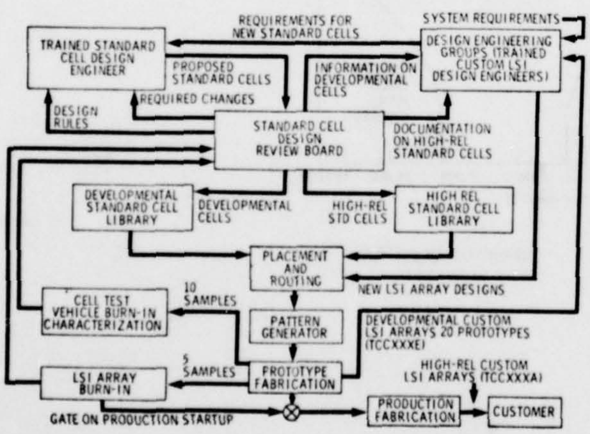


Figure 13. Custom LSI Array Development with Existing High-Rel Cells Plus the Introduction and Approval of New Standard Cells

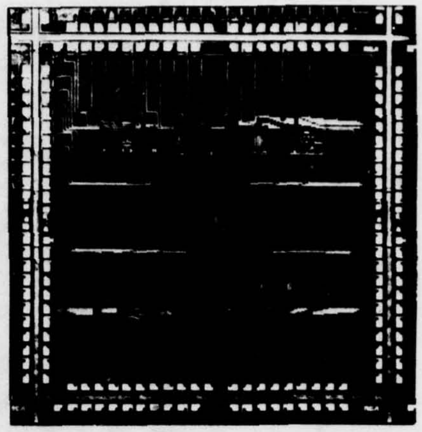


Figure 14. Test Vehicle Chip

integrated circuit line. Since 1971, he has been responsible for planning and coordinating monolithic LSI development and hybrid circuit activities for the Business Units of the RCA Government Systems Division.

PATTERN GENERATION METHODS
FOR MICROPROCESSORS

Lenward E. Holness
Mgr., Evaluation Dept.
Hughes Aircraft Co.

Outline

- Hardware methods
- Software methods
- Functional simulation example
- Summary

Hardware Pattern Generation Methods

- Hardware pattern emulation
- Algorithmic pattern generation
- Comparison

HARDWARE PATTERN GENERATION METHODS

ADVANTAGES	DISADVANTAGES
• EFFICIENT, I.E., REQUIRES LITTLE TEST SYSTEM OVERHEAD	• REQUIRES BOTH HARDWARE AND SOFTWARE EMULATION • EMULATOR MUST BE FASTER THAN THE TEST DEVICE • DIFFICULT TO GENERATE NON-ALGORITHMIC PATTERNS • MUST BE IMPLEMENTED IN LOW LEVEL LANGUAGE • DIFFICULT TO CHECK PROGRAM

COMPARISON METHOD

ADVANTAGES	DISADVANTAGES
• REAL TIME • LIMITED PATTERN STORAGE • REQUIRES INEXPENSIVE TESTER	• LIMITED TO TIMING AND SPEED CONSTRAINTS OF NGD • NOT LIKELY TO DETECT LOGIC, DESIGN OR DOCUMENTATION ERRORS • LIMITED FLEXIBILITY

Software Pattern Generation Methods

- Manual
- Learn
- Logic simulation
- Functional simulation

LEARNED RESPONSE METHOD

ADVANTAGES	DISADVANTAGES
• MODERAGE IMPLEMENTATION EFFORT • FLEXIBLE	• MUST USE KNOWN GOOD DEVICE • NOT LIKELY TO DETECT LOGIC, DESIGN OR DOCUMENTATION ERRORS • REQUIRES EXPENSIVE TEST SYSTEM

SOFTWARE PATTERN GENERATION

LOGIC SIMULATION

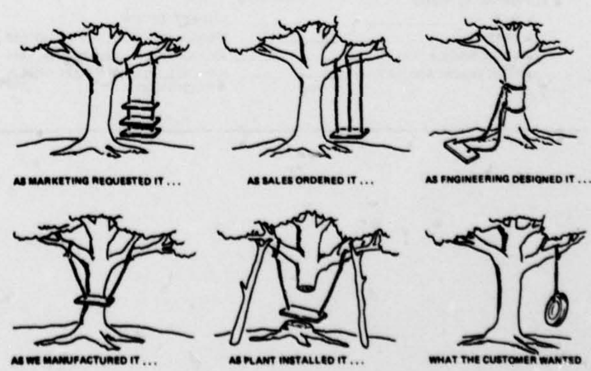
ADVANTAGES	DISADVANTAGES
• WILL THEORETICALLY COVER 99% OF THE DUT's CIRCUIT NODES? • WILL PROVE DUT MATCHES CIRCUIT SCHEMATIC • WILL USUALLY PRODUCE SHORT EFFICIENT PATTERN	• DOES NOT PROVE THAT DUT PERFORMS DOCUMENTED FUNCTIONS • REQUIRES THE CORRECT CIRCUIT SCHEMATIC • CANNOT BE USED TO GENERATE APPLICATION ORIENTED PATTERN • SIGNIFICANT IMPLEMENTATION EFFORT

SOFTWARE PATTERN GENERATION

FUNCTIONAL SIMULATION

ADVANTAGES	DISADVANTAGES
• CAN GENERATE APPLICATION ORIENTED PATTERNS • PROVES DUT PERFORMS DOCUMENTED FUNCTIONS • CAN GENERATE ADDITIONAL PATTERNS WITH MINIMAL EFFORT • PROVIDES CLOCK LEVEL AND BIT LEVEL DESCRIPTION OF MICROPROCESSOR OPERATION	• SIGNIFICANT IMPLEMENTATION EFFORT • CANNOT PROVE PATTERNS EXERCISE EVERY CIRCUIT NODE • LIMITED FAULT ISOLATION INFORMATION

THE PRODUCTION CYCLE

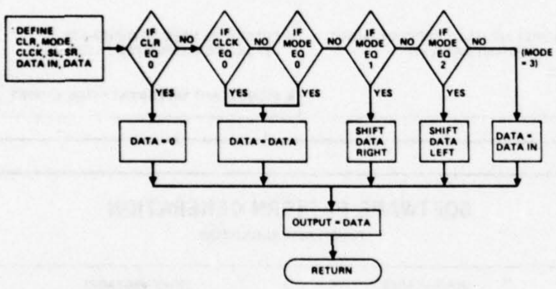


DEVICE DESCRIPTION EXAMPLE

FUNCTION TABLE FOR 54S194

INPUTS										OUTPUTS			
	MODE			SERIAL		PARALLEL							
CLEAR	S1	S0	CLOCK	SL	SR	A	B	C	D	Q_A	Q_B	Q_C	Q_D
L	X	X	X	X	X	X	X	X	X	L	L	L	L
H	X	X	L	X	X	X	X	X	X	Q_A	Q_B	Q_C	Q_D
H	L	L	X	X	X	X	X	X	X	Q_A	Q_B	Q_C	Q_D
H	H	H	H	X	X	a	b	c	d	a	b	c	d
H	L	H	H	X	r	X	X	X	X	r	Q_A	Q_B	Q_C
H	H	L	H	l	X	X	X	X	X	Q_B	Q_C	Q_D	l

FUNCTIONAL SIMULATION EXAMPLE (545194)



SUMMARY

SELECT TEST METHOD COMMENSURATE WITH THE APPLICATION RISK

- HARDWARE METHODS
  - HARDWARE ______ NOT OPERATIONAL
  - ALGORITHMIC PATTERN GENERATION ______ NOT EFFECTIVE
  - COMPARISON ______ LOW RISK, FIXED APPLICATIONS OR PRODUCTION
- SOFTWARE METHODS
  - MANUAL ______ NOT EFFECTIVE
  - LEARN ______ MEDIUM RISK, FIXED APPLICATIONS
  - LOGIC SIMULATION ______ PRODUCTION – FAILURE ANALYSIS
  - FUNCTIONAL SIMULATION ______ HIGH REL, MULTIPLE OR FLEXIBLE APPLICATIONS

MICROPROCESSOR SLASH SHEET DEVELOPMENT

W. Richard Scott
Supervisor
Jet Propulsion Laboratory

I was asked by the Workshop Chairman to discuss the preparation of military specifications for large scale integrated circuits. Yesterday, Col. Schlosser, SAMSO, and Larry Murphy, NASA, discussed a SAMSO/NASA "marriage" out of which would come a joint effort to accelerate the writing and release of Class S military specifications. JPL has a contract with the NASA Standard Parts Program Office to do just that – write specifications for the 1802, 1822, 1852 and 1853.

Lee Farnham of GE spoke yesterday of the evolution of the military specifications, starting with the JAN and progressing through the TX, TXV, Class A and finally Class S. He also imputed to them the ability to provide 1, 2, 3, 5 and 10 year parts respectively. I disagree with those numbers, per se, but further state that Class S as it exists today, is not adequate for high reliability LSI devices.

Due to the significantly increased complexity of semiconductor fabrication processes as well as chip design, there exist many new physical failure modes. That coupled with the immaturity of the whole LSI technology, lends the SSI and MSI techniques inadequate for LSI.

Before starting the draft of the MIL-M-38510/470, the 1802 slash sheet, JPL coordinated the specification requirements with the Air Force, Army, Navy, NASA, the semiconductor industry and both commercial and high reliability users.

Preparing such a specification begins with a characterization test program. We started with collection and review of vendor and user data, construction analysis, and further discussions with manufacturers and users. From there we developed a characterization test in which we developed a number of test vectors. We then ran sample devices through dc, switching, and functional tests, varying voltage, temperature, and frequency. After repeating these tests numberous times we selected what we felt to be the worst case vectors to which the device appears most error sensitive for a given set of timing conditions, voltages, and environmental constraints. This was an iterative process and from it we identified approximately 14,000 test vectors. These become part of the screening and qualification requirements.

The specification identifies the parameters, parameter limits and test conditions. It is designed to examine for pattern sensitivities and establishes timing, power and temperature levels. Burn-in circuits and conditions are defined as are visual inspection criteria.

Before completing the draft, and hoping to shorten the usual 12 to 18 month coordination cycle for military specifications, we held a precoordination conference a month ago. Present were all the manufacturers of the 1802 (RCA, Hughes, and Solid State Scientific) as well as RADC and SAMSO. Because of their work on LSI, we also invited Sandia Laboratories, NASA, Hughes Aerospace, Macrodata Corporation, and Continental Test Laboratories.

The deliverables under this contract include the draft specifications as well as test tapes programmed with all the test vectors and parameter measurements. These tapes are written for immediate use on the Tektronix S3260. Copies of these will be available either through the NASA Standard Parts Program Office at MSFC or through RADC.

In conclusion we feel: 1) that complete characterization testing must be accomplished before a specification can be written; 2) the microprocessors have several serious limitations the most notable one of which is their lack of testability; 3) the ability to perform functional and switching test is seriously limited by most test systems; 4) no complex LSI can be expected to meet all the requirements of MIL-M-38510, Class S, as they now exist; and, 5) because of all the subtle and not so subtle problems encountered in characterizing and specifying microprocessors, there is an urgent need for a single clearing house to collect, analyze, and disseminate the LSI information to all agencies.

Outline

- Background
- Characterization test
- Detail specification
- Precoordination meeting
- Deliverables
- Conclusions and recommendations

Background

- Class S
- Complexity
- Technical immaturity
- Coordination

Characterization Test Program

- Basic vendor data
- Characterization process
- Characterization results

Specification Details

- Parameters
- Pattern sensitivities
- Functional test pattern
- Timing voltage, temperature
- Burn-in requirements and circuits
- Visual criteria

Precoordination Conference

- RCA, HAC, SSS
- SAMSO, RADC
- NASA/MSFC, NASA/GSFC, JPL
- Sandia Laboratories
- Hughes Aerospace
- Macrodata Corporation
- Continental Test Labs

Deliverables

- Draft MIL-M-38510/470
- S3260 test program tape

Conclusions

- Complete characterization
- Device limitations
- Test system limitations
- MIL-M-38510, Class S
- Clearinghouse for LSI information

MEMORY DESIGN AND TESTING FOR HIGH RELIABILITY APPLICATIONS

Dr. Joseph S. Bravman
Director, Electronic Programs
Fairchild Space & Electronics Co.

Abstract

During the past several years memory technology has become a critical part of modern space and military digital systems. This is a by-product of the microprocessor revolution and the sophistication required for onboard computation in increasingly complex miniaturized systems.

The equivalent gate count of these memory devices is so large as to overshadow the equivalent gate count in the remaining digital circuitry and for this reason reliability computations based upon MIL-HDBK-217B are extremely sensitive to improvements in memory reliability technology.

Part screening must be employed. A hierarchy of screening level begins with MIL-M-38510 and can accept lesser parts with proper screening and burn-in test performed by the device vendor or testing laboratory. This allows the use of optimistic quality factors from the MIL-HDBK-217B reliability model.

Additional cost-effective tests which need to be developed are described herein.

As new technologies such as magnetic bubbles emerge in operational military systems, new specifications will be developed to deal with their screening and burn-in requirements. Other technologies which are basically similar to existing MOS and bipolar devices should require only minor modifications to the existing MIL-STD-883 format.

Introduction

During the past several years memory technology has become a critical part of modern space and military digital systems. This is a by-product of the microprocessor revolution and the sophistication required for onboard computation in increasingly complex miniaturized systems. Because of the repetitive nature of memory structures, chip densities for memories are the largest in the LSI and VLSI domain. The I/O problem associated with these large devices is minimized by binary address lines or by serial access. Thus, the usual limitations in chip complexity that place an upward bound on single chip size have been minimized and future growth beyond 65 kilobits is expected in the immediate future.

In addition, current and future systems require several thousand words of processor instructions stored in ROM, 1000 to 2000 bits of scratch pad RAM, possibly a megabit of additional RAM and up to 10^8 bits of bulk storage. The system design constraints of cost, size, weight, power and reliability are focusing attention on solid state memories to fill these needs. The present state-of-the-art utilizes primarily silicon technology. However, other specialized devices (e.g., magnetic bubble, crosstie and FAMOS memories) are soon to be parts of operational space and military systems. (Figure 1)

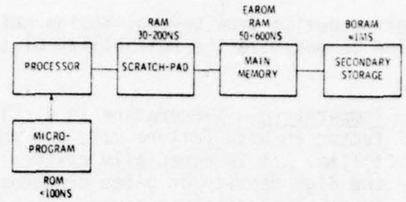


Figure 1. Memory Hierarchy

The equivalent gate count of these memory devices is so large as to overshadow the equivalent gate count in the remaining digital circuitry and for this reason reliability computations based upon MIL-HDBK-217B are extremely sensitive to improvements in memory reliability technology. That improvement has three sources:

- Improvements in device processing and packaging technology
- Improved screening and burn-in procedures
- Better design guidelines and operating environment

Design Trends

Today's engineer has a choice of a variety of memory products which are built from several MOS and bipolar technologies. Each has its advantages and disadvantages and becomes more or less competitive as technology develops. In general, the choice for a RAM is made based upon access time requirements, storage capacity and cost. The table below shows general trade-off parameters utilized in the selection process. ROMs, PROMs, EAROMs are a bit more controversial in their selection criterion. Most processor instructions and look-up tables are stored in ROMs. However, schedules often require use of PROMs to facilitate last minute changes in software. In addition, avionic prime and test equipment usually require flexibility which can be best achieved utilizing PROMs. EAROMs are in general a poor choice for program storage and scratch pad applications. However, they provide an attractive alternative to magnetic memories or a battery backup for non-volatile storage data. (Figure 2)

TYPE	TECHNOLOGY	+	-
RAM	MOS	LOW COST	SLOW, RADIATION SENSITIVE
	BIPOLAR	FAST, LESS RADIATION SENSITIVE	MORE EXPENSIVE, HIGH DISSIPATION
	CCD	HIGH DENSITY LOW POWER	SERIAL ACCESS, REFRESH REQUIRED
ROM	MOS, BIPOLAR	PERMANENT DATA	NON-FLEXIBLE
PROM	UV ERASABLE, FUSIBLE LINK	FLEXIBLE	POSSIBILITY OF PARTIAL VOLATILITY
EAROM	MNOS	"NON VOLATILE" STORAGE	LIMITED CYCLE LIFE, POSSIBILITY OF PARTIAL VOLATILITY

Figure 2. Memory Selection Criteria

At FSEC, our application of memories follows the general guidelines described above on space and avionic programs. Both prime and test equipment are involved for each program.

For any given device type several design guidelines are applied to maximize the reliability of the device.

- Temperature - Temperature is a critical factor in both failure rate and volatility. It is especially critical since the high density of gates produces a large power dissipation even with MOS devices. Dissipation values of 1/2 watt and more are common, and memory hybrids or circuit boards can typically dissipate 5-10 watts. Recent military guidelines, especially those from the Navy, encourage junction temperatures of 110°C or less even in a 71°C (MIL-E-5400 Class II) environment. Board designs can utilize laminated metal or metal core construction to improve heat flow to the board edges where conduction or forced air cooling is provided. Techniques utilizing ceramic board or ceramic bar technology shows promise for improved heat flow. A selective "power-down" mode can also be employed to reduce dissipation during idle times under the control of the processor.

- Timing Criticality - While not as important as temperature, timing parameters are both related to internal device operation and the device-circuit interface. They are a function of many parameters which include device processing effects and the device operating environment. Breadboard tests demonstrate design adequacy for a nominal set of values, but proper worse case and sneak circuit analyses must be performed to insure reliable operation for the duration of the program. In some cases, device screening has shown that a fail condition can exist within an otherwise acceptable range in the variation of a parameter between minimum and maximum values.

- Shielding - This factor is particularly important where ultraviolet erasible PROMs are utilized. Foil tape is used to guard against unwanted ultraviolet leakage into the device window. In addition, many common MOS devices, especially PROMs and EAROMs, are susceptible to radiation and until hardened devices are developed, suitable shielding must be provided.

- Use of Redundancy - A common way to improve the system reliability is through the use of redundancy. Many military systems contain complex built-in-test routines which verify the integrity of both RAM and ROM devices. Test failures will automatically trigger the switchover to backup memories or an entire backup processor. Degraded mode assessment is another technique to create fail soft conditions when portions of the RAM or ROM fail.

Device Defects

While many of these devices are reasonably new on the scene, failure histories are being developed by Rome Air Development Center and industry. The table below summarizes some preliminary analyses conducted by RADC on LSI failures for various technologies. While all of these devices are not memories, the data is representative of expectations for memory devices. The leading defect varies with device technology, however, contamination is significant in all cases and other defects could stem from registration problems with these large structures. The former factor tends to stress the importance of precap visual, SEM, and leak testing in screening. The RADC study also tabulated packaging failure data. These results are typical of the extensive work that is continuing at the RADC Reliability Analysis Center. (Figure 3 and Figure 4)

SURFACE DEFECTS
- CONTAMINATION
- FOREIGN MATERIAL STRAY PARTICLES
- INVERSION CHANNELING
- SURFACE LEAKAGE

BULK DEFECTS
- CRYSTAL IMPERFECTIONS
- CRACKED, CHIPPED DIE

OXIDE DEFECTS
- GATE OXIDE PINHOLES
- FIELD OXIDE PINHOLES
- OXIDE FAULT
- OXIDE SHORT/BREAKDOWN
- PASSIVATION DEFECT

DIFFUSION DEFECTS
- DIFFUSION ANOMALY
- DIFFUSION SPIKE/PIPED JUNCTION
- ISOLATION DEFECT
- MASK FAULT

METALLIZATION DEFECTS
- OPEN AT OXIDE STEP
- OPEN AT CONTACT WINDOW
- OPEN/NOT SPECIFIED
- SHORT/INTERLAYER METAL
- SHORT/NOT SPECIFIED
- PITTED/CORRODED
- SMEARED/SCRATCHED
- ELECTROMIGRATION

INPUT/OUTPUT CKT. DEFECTS
- EXCESSIVE INPUT LEAKAGE
- INPUT CIRCUIT SHORT
- EXCESSIVE OUTPUT LEAKAGE
- OUTPUT CIRCUIT SHORT

Figure 3. Die Related Failure Modes Defect Classification

FAILURE CLASSIFICATION	LSI CMOS %	LSI NMOS %	LSI Al GATE PMOS %	LSI Si GATE PMOS %	LSI Si GATE PMOS (EAROM) %	LSI STD TTL %	LSI SCHOTTKY TTL %
SURFACE DEFECTS	50	37	38	38	42	8	43
BULK DEFECTS	0	0	0	4	0	0	0
OXIDE DEFECTS	38	44	20	0	0	33	3
DIFFUSION DEFECTS	[illegible]	[illegible]	13	0	0	0	3
METALLIZATION DEFECTS	12	17	[illegible]	33	8	58	51
INPUT/OUTPUT CKT. DEFECTS	0	0	1	22	0	6	0
TOTAL NUMBER OF DEVICES	16	12	176	18	13	[illegible]	[illegible]

SOURCE: RADC MICROCIRCUIT DEVICE RELIABILITY MDR-4 SUMMER 1974

Figure 4. Die Related Failure Modes: LSI

Part Screening

All parts that are utilized in space and military systems receive a series of screening and burn-in tests which are in general in accordance with MIL-STD-883 as amended. In general, a hierarchy is established which considers parts in the following order of preference.

1) MIL-M-38510

2) MIL-STD-883 (Level S or B)

3) Vendor equivalent to MIL-STD-883B with additional screening.

4) MIL temperature range part with additional screening. If possible, this will include precap visual performed by the vendor.

Utilizing these guidelines reliability factors are developed consistent with MIL-HDBK-217B. The quality factor from that model is very sensitive to the maturity of the part and the adequacy of the screening and burn-in process. In general, when the above steps are taken π_Q factors (which range from 2.5 to 150) can be maintained in the 2.5 to 5 range. Several testing laboratories have emerged which perform sophisticated screening and rescreening of these sophisticated components. The table below illustrates the categories of tests that are performed on each generic type of memory. (Figure 5)

TESTING REQUIREMENTS	RAM	ROM	EAROM	COMMENTS
1) DC PARAMETRIC TESTS	X	X	X	TO MANUFACTURER OR USER SPEFICIATIONS
2) HIGH SPEED FUNCTIONAL (PATTERNS)	X	X	X	SEE LIST OF PATTERNS AVAILABLE BELOW
3) TRUTH TABLE (SUPPLIED ON PAPER TAPE, ASCII CODE)		X		
4) SLOW SPEED FUNCTIONALITY TESTS		X		
5) VOLATILITY TESTS			X	

Figure 5. Testing Techniques by Device Type (RAM, ROM, EAROM)

One of the most important tests involves the writing and reading of memory cells in the array. This test is critical since it checks the basic functioning of the component. It also is extremely time consuming for large arrays with relatively slow access times. A worse case pattern would require $2N^2$ tests where N is the number of memory cells. For large MOS memories this testing could take several minutes which can result in long and expensive screening tests. Other patterns have been developed which are shown in the next table. However, these require an understanding of the detailed digital design of the memory in order to insure that an adequate test is performed. This may be derived either analytically or by experimentally testing a group of samples with several patterns to determine which one discovers the largest number of failures. (Figure 6)

SLIDING DIAGONAL SHIFTING DIAGONAL	$N^{3/2}$	GALROW/GALCOL	$4N^{3/2}$
MARCH SCANREV	5N	REFRESH	9N + 27N WAIT
ADDRESS COMPLEMENT MASEST	4N	ADSEL	13N
PING PONG GALLOP II	$2N^2$	CSZRO, CSONE	8N
CHECKERBOARD	8N	ZRONE	4N
WALK WALKPAT	N^2	ROWBAR/COLBAR	24N
GALLOP	$2N^2$	WALKCOL	$2N^{3/2}$
		DOUBLE COMPLEMENT ADDRESS	7N

Figure 6. Pattern Library

In addition to the more common tests which are dictated by MIL-STD-883, there are other tests or other criterion which may be addressed to determine their effectivity in improving the failure rate of the selected device.

- Volatility - Volatility is a critical parameter for PROMs and EAROMs. In general, temperature is involved as a discriminant even with fusible link PROMs.

- Thermal Resistance - Since most memory devices dissipate substantial amounts of heat, a proper bond between the die and the package is critical for uniform heat transfer. The presence of significant voids can cause device overheating as well as thermal gradients and stress on the chip. This parameter could be measured either by examining an individual P-N junction or possibly by measuring the incremental change in supply current with increased dissipation. The thermal resistance also includes package thermal spreading and conductive pads to the circuit board.

- Current Transients - Switching phenomenon within the device can result in large current spikes which can cause problems within the chip or at the system level. Suitable criteria would determine acceptable limits for such current transients.

In general, the total screening and burn-in requirement raises the basic commercial part price by at least a factor of three (exclusive of lot charges) but the benefit in improved failure rate is many times that amount. As new technologies such as magnetic bubbles emerge in operational military systems, new specifications will be developed to deal with their screening and burn-in requirements. Other technologies which are basically similar to existing MOS and bipolar devices should require only minor modifications to the existing MIL-STD-883 format.

As a designer and manufacturer of digital systems, we are faced today with a need for large and reliable memories since they often dominate the MTBF of the overall processing system. The solutions to this problem are addressed as a three pronged approach that utilizes proper design guidelines, improvements in IC manufacturer's technologies and processes and cost effective but comprehensive screening and burn-in by the device supplier or a screening laboratory. Since LSI technology is extremely dynamic today, all three factors must be addressed and updated continually to be sensitive to the needs of mission assurance. However, testing must be truly cost effective in this era of declining budgets, Designed to Cost, and total Life Cycle Cost.

When these factors are successful, qualification, burn-in and acceptance testing at the system level are cost effective and lead to a successful program and mission.

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3. Annual Report (Calendar Year 1977) - Advisory Group on Electron Devices - Office of the

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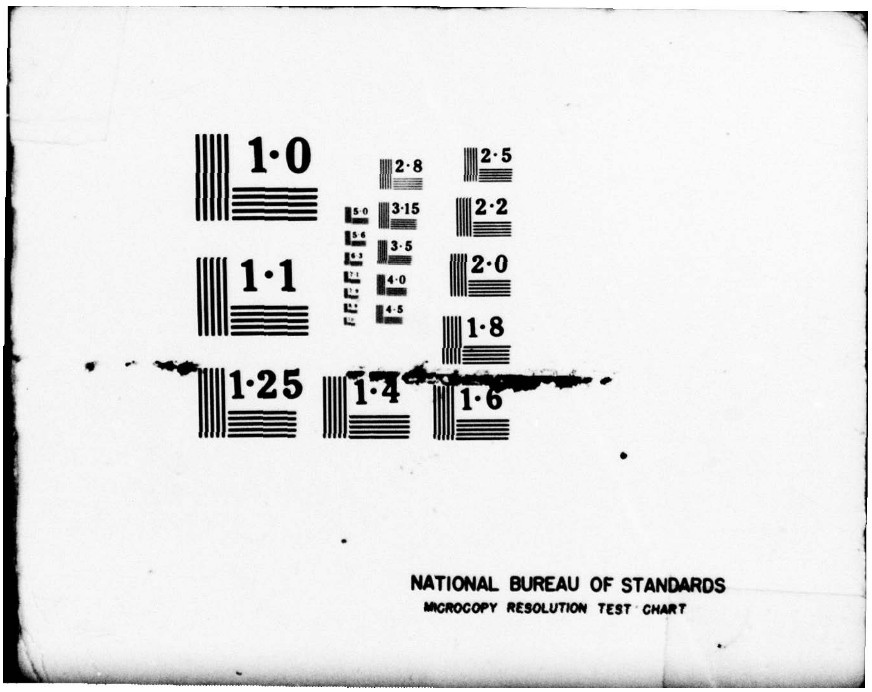
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NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Under Secretary of Defense Research and Engineering.

4. NASA CR-137889 dated June 20, 1976 - Computer Technology Forecast Study for General Aviation by Charles L. Seacord and Darrel Vaughn - Honeywell, Inc.

5. Military Specifications/Standards:

   MIL-HDBK-217B
   MIL-M-38510
   MIL-STD-883

6. Users Handbook to Semiconductor Memories by Eugene R. Hnatek, John Wiley and Sons, 1977.

CLASS S LSI PLANS

Alan J. Carlan
The Aerospace Corporation

Abstract

The complexity of LSI circuits and inability to perform functional testing under all rated operating conditions, create new problems in reliability assessment, qualification and development of detailed specifications for high reliability LSICS for use in space and launch vehicle applications.

At present, military microcircuit specifications for Class S do not include adequate requirements for qualification and acceptance of complex LSIC's. This paper will describe some of the planned approaches toward extending existing requirements as well as development of new military requirements for use of LSIC's in space and launch vehicle applications.

Introduction

- Increased usage of large scale integrated circuits in space, satellite and launch vehicle systems is anticipated. To assure mission success, these systems require the use of Class S reliability parts.
- However, reliability assessment and qualification of LSICs are difficult due to their complexity and inability to perform complete functional testing under all rated operating conditions.
- This paper will briefly review the present system for qualification of microcircuits, some considerations and concerns regarding LSICs and the planned approaches toward extending the Class S requirements to include LSICs.

The QPL System for Class S Microcircuits

- Manufacturers obtain Class S line certification.
- A detailed specification (M38510 "slash" sheet) is prepared and issued.
- A manufacturer who desires that a given part be placed on the QPL must contact the qualifying activity and submit the data required by MIL-M-38510D. The qualifying activity then issues an authorization to test.
- For Class S, two device lots are subjected to the qualification testing as required by Method 5005 of MIL-STD-883B and the applicable detailed specification. The manufacturer must certify that the material and physical dimensions of the microcircuits comply with the general and detailed specifications.
- After satisfactory completion of the tests and approval by the qualifying activity, the parts are placed on the QPL.

Considerations and Concerns Regarding Use of LSICs in Space, Satellite and Launch Systems

- Potential advantages
  - Lower system cost
  - Improved system performance
  - Facilitates expanded system capability
  - Reduces power consumption
  - Reduces weight
  - Fewer interconnections may improve system reliability
  - Use of radiation shielding is simplified due to small size of LSICs
- Potential disadvantages
  - Use and reliability experience in space systems is almost nonexistent.
  - A realistic base of reliability data is difficult to obtain due to newness of processes and device designs, for example: several "A" revisions are appearing for microprocessors, RAMs are undergoing one or more "shrinks."
  - Rapid obsolescence of designs may make replacement parts difficult to obtain.
  - It is impossible to completely test LSICs under all rated operating conditions and inputs.
  - For custom LSICs; design, qualification and delivery of acceptable parts may be costly and time consuming.
- Specific reliability concerns
  - Many LSICs are new or not widely used, thus evaluation and test history is very limited and unproven parts may be designed into systems.
  - Inability to perform complete functional testing devices may be accepted with unknown failure modes. Circuit sensitivities may not be found, these may occur as a result of a unique combination of voltages, combinatorial patterns, noise, temperature effects, etc.
  - Accelerated functional testing in the traditional sense is difficult or impossible to perform e.g. many LSICs do not function at 200°C.
  - LSICs have thousands of active devices, interconnects, contacts crossovers, as well as multiple

conductor layers separated by thin dielectrics. A failure in any of these can cause failure of the entire circuit.

- Due to the complexity of the LSICs, workmanship and other defects are difficult or impossible to find during device screening. Defects in, for example, thin dielectric may fail in a time dependent mode, these weak dielectrics may not be accessed during functional testing or burn-in.

- Physical dimensions of the components of an LSIC are getting smaller: for example:

  5 years ago, metal line width were of the order of 10 μm. LSICs on the drawing boards currently have dimensions in the 1 to 3 μm range.

- The potential for defects and the inability to perform visual inspections on these components with small dimensions coupled with the increasing use of multiple dielectric and conducting layers is enormous.

- The very high density LSICs may be more susceptible to ESD damage due to use of thinner dielectrics and/or smaller dimensioned components (e.g. junctions). These may not be able to dissipate transient energies without sustaining damage.

- Custom LSICs have all of the concerns of standard LSICs but lack extensive test, reliability and functional performance history. Each custom LSIC is a unique system.

Perhaps this workshop can provide answers to the following questions relating to custom LSICs:

- Should custom LSICs be included in the military QPL system?
- If this is desirable, how can it best be accomplished?

Plans for Extending Class S LSIC Requirements

- Use of systems approach
  - Design reviews
  - Fault analysis
  - Sensitivity analysis
  - Testability analysis
- Requirements for "built-in" testability
  - Establishment of a testability "figure of merit" to be used as a measure for accepting new LSIC designs.
- Extension of the concept of line certification to that of "technology certification" which would include not only the present requirements such as:
  - Product assurance program
  - Manufacturing baseline
  - Manufacturing change control

  But would add evaluation of:

  - Design rules
  - Cell libraries
  - CAD and design philosophy
- Expand the existing concept of wafer lot acceptance to include use of reliability test devices (RTDs). These would be designed for use with each technology and mask sequence of interest. The RTDs would be "dropped-into" several sites on each device wafer. The RTD test patterns would include the following (these are also listed in the draft of MIL-STD-1547).
  - Basic electrical parameters of the components of the LSIC.
  - Dielectric test structures for electrical dielectric defect tests (pinholes) and dielectric breakdown voltage.
  - Thermal stability (C-V stress test patterns) – tests for contaminated oxides.
  - Junction and device breakdown voltage.
  - Metal continuity and stability (absence of electromigration) over many circuit surface features (steps).
  - Metal to semiconductor and polysilicon contacts for stability under current temperature stresses.
  - Sheet resistance of diffused or implanted regions,
  - Critical circuit cells.
  - Line width and gap controls.
  - Dielectric thickness controls.

The test patterns for dielectric defects, metal continuity and polysilicon and metal contacts would contain large numbers of structures equivalent to the structures within the LSIC. The RTDs are capable of evaluating the components of the LSIC as each test structure would be designed to be accessible for electrial testing. They may also be packaged up for environmental, radiation, or accelerated test as components of the LSIC.

- Expand the screening tests based on data from:
  - Design review
  - Fault analysis
  - Testability analysis
  - Sensitivity analysis
  - Characterization

  To include:
  - Use of voltage stresses
  - Pattern testing
  - Monitored dynamic burn-in (MIL-M-38510 will be revised to provide for more than one burn-in)
  - Extend functional tests based on the above analysis.
- Re-evaluate the visual inspection requirements and possible alternatives. These may include:
  - Low power visual
  - High power inspection of critical and typical areas of the chip on a sample basis.
  - Use of RTDs from each device wafer.
  - Use of accessible test devices on each LSIC chip.

Recommendations and comments from the participants in this workshop will be most welcome.

SOME PRACTICAL PRINCIPLES TO ACHIEVE HIGHER HYBRID MICROCIRCUIT RELIABILITY

Jerome Fishel
President, Circuit Technology Incorporated

Introduction

The following suggestions have proven to be important when the objective is to manufacture relatively small runs of hybrid microcircuits with high reliability.

State of the Art Technology

Do not let the Customer push you into situations where your design and/or manufacturing process is new. Stay well within those design concepts and good manufacturing practices that you are well acquainted with and have proven successful.

Mature Devices

Use only those devices which have been mass produced by two or more Suppliers for a minimum of two years. While your restraint may annoy some designers, it will insure continued supply and quality.

Development Selection

While some modest selection of some parameters is acceptable, avoid highly selected components.

End of Life

The circuit designs must be such that performance will not suffer even when a large number of the devices used have reached an end of life values.

100 Percent Electrical Inspection of Devices

It is important to plan ahead so that all devices to be used can be thoroughly tested over the operating temperature range prior to acceptance. This initial investment will result in a major improvement in the manufacturing yield and the quality.

Printed Versus Chip Resistors

Stay with resistors that are screened and fired on the substrate. Purchased thin film resistor chips have proven troublesome.

Circuit Partitioning

It is essential that each package contains a function that can be electrically characterized and tested properly. Try to avoid highly specialized instrumentation or correlation problems will result.

Substrate Partitioning

Avoid excessive complexity by using two or more substrates in one package. This avoids a number of problems associated with large substrates. It also provides an opportunity to pretest each substrate section prior to committing it to its package.

Process Compatibility of Components

It has been our experience that incoming material that appeared quite normal proved to have some subtle defects when used in manufacturing. By processing a sample of each lot of material received through the manufacturing sequence, we can determine whether such anomalies will arise.

Latent Problems with Incoming Material

One must understand each device used well enough to anticipate what latent problems are typical and to devise a specific accelerated test.

Lot Integrity of Incoming Material

Wherever possible, purchase semiconductor devices as uncut wafers. Each wafer becomes a homogeneous lot and can be readily reprobed, and characterized. Capacitors, packages, preforms and other such material should also have lot integrity.

Conductor and Dielectric Printing

To insure good conductivity and adequate gold for eutectic bonding, conductor and bonding pads should be double printed. To avoid pin holes and thin spots in the dielectric, double or triple printing of dielectric is advisable.

Resistor Trimming

Sand abrasion is preferred to insure freedom from damage in the kerf. Laser trimming is useful to perform modest "active trims" where only a small amount of resistor material is to be removed.

Production Yields

The design and manufacturing procedure should be such that the production yield will be acceptable without the need for any significant repairs. A well designed product using the proper material and well thought through manufacturing processes should result in high yield. I am not impressed with people who claim that their process allows one to make repairs easily.

Process Forgiveability

Accept the premise that we will have high labor content and human beings are less than perfect. The manufacturing process must have considerable margin for error. One must study each manufacturing step to determine where the human operator most often may make an error.

In-Line Inspection

It is necessary to be as diligent in the development of 100 percent inspection methods as one is diligent in developing the manufacturing process. Inspection must be done immediately and the result made available immediately so that effective corrective action can be taken.

Die Attach

Use gold silicon eutectic die bonding wherever possible. Use gold filled epoxy where necessary to provide a mechanical bond. Avoid passing current through epoxy.

Capacitor Attach

Side braze all capacitors whose length is 100 mils or less. For larger capacitors, use non-conductive

epoxy for mechanical attachment to the substrate and wire bonding for electrical connection.

Cleaning and Push Test

Wherever possible, a small tool should be used to apply a modest pressure on all attached devices. Poorly attached devices can be detected in this fashion. Also, a small tool can be used to remove any partially attached particles from around each device.

Substrate to Package Attachment

To insure low thermal resistance and mechanical strength, gold/germanium or gold/tin should be used to attach the substrate to the package. Where the substrate is to be attached to vertical leads, it should be fit over the pins and the same materials can be used for attachment. It is understood that the substrates will have high adhesion material printed on the backs and around the holes.

Wire Bonding

A 100 percent pull test should be performed on all wires to a level of two or three grams, depending on the device and wire size.

Preseal Bake and Sealing

All devices should be thoroughly baked for a minimum of six (6) hours at 150°C in vacuum. Sealing should be accomplished by a welding process without any preforms in a dry box which is controlled to for less than 30 ppm water vapor.

Gas analysis should be performed on a sample of each sealing lot.

Sequential Burn-in to Zero Failure

The burn-in should be a sequence in which the circuits are tested after each interval. The criteria should be such that a given lot must go through two cycles in the sequence without any failures. In addition, a maximum percent defect allowable should be instituted.

Destructive Physical Analysis

Just prior to shipment, one percent of the lot should be subjected to a thorough DPA to insure that parts have not been damaged during sealing, environmental test and burn-in.

PIND Test

While PIND test does detect particles, it is very inconsistent (non-repeatable) and may be rejecting circuits which have harmless particles. I would suggest we try to refine this procedure to overcome these limitations or consider the Mann Test which subjects the part to vibration and shock while operating, and detects anomalies.

Life Test

I believe the operating life test should exactly simulate the actual use conditions both electrically and mechanically. This may involve frequent interruptions of power or power surges, changes of environmental temperatures and variations of load. Also, the test should continue for a minimum of three thousand hours.

Step Stress Life Test

A series of step stress conditions should be applied to a second group of parts to induce failures. Analysis of these failures must determine whether normal things have happened or whether we have uncovered a design or device fault which needs correction.

In conclusion, it is my opinion that a hybrid circuit, like any other manufactured component can provide a useful function in a reliable fashion if designed and manufactured properly.

JPL HYBRID EXPERIENCE

John deJong
Jet Propulsion Lab

- Mariner Mars 1971 (1968)

  Transistor arrays

  Diode arrays

- Viking lander GCMS instrument (1969)

  J FET analog commutator switches

  Transistor arrays

  Diode arrays

  Operational amplifiers

  MOS clock drivers

- Mariner Venus/Mercury 1973 (1970)

  J FET analog commutator switches

  Transistor arrays

  Diode arrays

  Plated-wire-memory digit/word drivers and sense amps

- Viking orbiter (1971)

  Hi speed ADC ladder switches

  J FET analog commutator switches

  Transistor arrays

  Diode arrays

  Plated-wire-memory digit/word drivers and sense amps

- Voyager (1973)

  Transistor arrays

  Diode arrays

  Large scale digital hybrid memories

- Vortex instrument (1976)

  Large scale digital hybrid system

- Galileo (1978)

  Transistor arrays

  Diode arrays

  CCD camera electronics

  Large scale digital hybrid memories

Voyager Hybrid Memory Chip Screening

- Standard CD4000A components
  - Dice procured from RCA with traceability to the evaporator run
  - SEM requirements were GSFC 311-P12A modified as agreed by RCA and NASA
  - Visual requirements were MIL-STD-883, Method 2010, Level A (included 100 percent JPL die sort inspection)
  - Electrical testing
    - STD wafer probe by RCA
    - DC parameters by Teledyne (die level at 25^{o}C)
    - Propagation delay by Teledyne (die level at 25^{o}C)
  - Post electrical visual die sort per MIL-STD-883, Method 2010, Level A
  - CD4061 RAM components
    - Dice procured to commercial quality criteria
      - No wafer traceability
      - Dice visual requirements were MIL-STD-883, Method 2010, Level B modified (as defined by RCA)
      - JPL visual die sort inspection provided segregation of procured die into Level A, Level B, and Level C categories
    - Electrical testing (visual A components)
      - Dc parameters by Teledyne (die level at 25^{o}C)
      - Ac parameters by Teledyne (die level at 25^{o}C)
      - Gapat pattern testing
      - Read access time measurement testing
    - Post electrical visual die sort per MIL-STD-883, Method 2010, Level A

Galileo Hybrid Memory Chip Screening Plan

- Standard CD4000B components
  - Wafer traceability to evaporator run (SEM)

- RAD harness verification of product line
    - Sampling program or
    - Verification of process
- Visual requirements to MIL-STD-883, Method 2010, Level A (JPL audit)
- Electrical testing
    - Wafer probe by manufacturer
    - Functional testing after hybrid assembly by hybrid manufacturer

- 1024-bit status CMOS RAM
    - Dice procured from manufacturer with traceability to diffusion runs
    - Wafer slice to verify wafer metalization (SEM)
    - 3 packaged parts from each wafer to verify functionalism and leakage current after radiation
    - Wafer probe utilizing the manufacturer's packaged component, pre and post burn-in tapes
    - Visual inspection to MIL-STD-883, Method 2010, Level A

Comparison of Voyager Versus Galileo Approach

	Voyager FDS	Galileo CDS
Total fabricated bits	1,048,576	3,686,400
Total dice procured	16,500	4,000
Dice cost	$288,750	$101,000 (est)
Dice testing cost at hybrid contractor	$21,000	Included above
Dice testing program	Minimal - (dc test plus Galpat and read access time measurements at 25°C)	Good - (full parametric ac and dc testing at 25°C - complete wafer traceability including radiation harness verification and SEM analysis)

Conclusion/Recommendation

- Semiconductor chip manufacturer's are able to provide improved screening options at a lower cost than screening and testing options which utilize a hybrid manufacturer's dice testing capabilities
- The dice procured from the manufacturer should be of a quality that can be directly assembled into the hybrid, thus reducing potential component handling problems and hybrid assembly cost

CLASS "S" HYBRID MICROELECTRONICS COMMITTEE

Donald L. Fresh
Technical Staff
The Aerospace Corporation

SURVEY CONDUCTED BY:

Col. W.L. Schlosser, Director
Acquisition Support
SAMSO

Dr. M.T. Weiss, General Manager
Electronics & Optics Division
The Aerospace Corporation

RESULTS PRESENTED TO:

Lt. Gen. T.W. Morgan
Commander
SAMSO

Objective of Survey

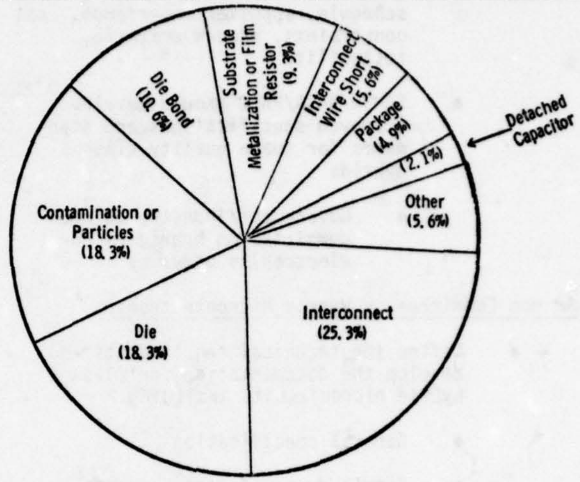
- To determine the status of hybrid technology in industry and the implications of this technology on SAMSO programs
- To investigate the advantages and disadvantages of hybrid usage with particular emphasis on reliability
- To make recommendations for future actions to assure hybrid reliability for space applications

Usage of Hybrids

- Rapidly increasing use of commercial and consumer electronics
- Increasing use in space systems
    - DSCS III hybrid usage
        - Per spacecraft — 63 types, 1,342 units
        - GE fabrication — 46 types, 371 units
        - CTI fabrication — 5 types, 278 units
        - Teledyne fabrication — 1 type, 278 units
    - Space Shuttle Orbiter
        - Used in 37 subsystems
        - 35 vendors

        OV101 total - 12,580 hybrid units

        OV102 total - 15,982 hybrid units



FAILURE MODES

Technical and Reliability Considerations

- IC and transistor/diode chips
- Substrates
- Chip and wire attachment
- Packages
- Fabrication cleanliness
- Particle contamination control
- Testing

Summary Conclusions and Recommendations

- Increasing use of hybrids in SAMSO systems inevitable
    - Size and weight are primary driving factors
    - Design flexibility, technical requirements, cost and reliability are important factors
    - Hybrid usage should result in increased performance for SAMSO systems
- SAMSO must take active steps to assure compatibility of hybrid usage with space reliability and performance requirements
    - SPO should review all aspects of hybrid development, vendor selection, fabrication and test
    - Testing of complex hybrid modules may require special development
    - SPO should control hybrid complexity to be compatible with development

schedule, supplier experience, cost constraints, rework criteria, testability

- SAMSO/NASA/RADC should develop improved specifications and standards for space quality Class S hybrids
    - Government/industry ad hoc committee on hybrid microelectronics underway

Ad Hoc Committee on Hybrid Microelectronics

- Define the technical requirements and develop the documentation for Class S hybrid microcircuits including:
    - General specification
    - Detailed specification format
    - Layout and design requirements
    - Manufacturer certification
    - Qualification and quality conformance requirements
    - Screening procedures
    - Unique test methods
- 21 members; Chairman, D.L. Fresh

The Aerospace Corporation	1
AFML	1
DESC	1
JPL	1
NASA	3
RADC	1
SAMSO Contractors	12
SANDIA	1

Subcommittees

1. General Specification

J. Farrell**	RADC
L. Schneider*	TRW/MM
S. Caruso	NASA/M
D. Hill	DESC
J. Whittington	HAC

1A. Layout/Design/Construction

E. Cormier**	GD/C
D. Loescher*	Sandia
D. Lapitz	TRW

1B. Organics/Polymers

S. Caruso**	NASA/M
R. Rohal*	NASA/L
AFML	AFML

2. Qualification/Screening Procedures

J. Hilibrand**	RCA/GS
P. Dick*	GE/VF
D. Cole	GE/U
J. Farrell	RADC
D. Hill	DESC
R. Rohal	NASA/L

3. Test Method-Active Chips

P. Eisenberg**	Northrop
J. deJong*	JPL
P. Dick	GE/VF
J. Hilibrand	RCA/GS
D. Loescher	Sandia

4. Test Method-Passive Chips

E. Zimmerman**	Boeing
D. Cole*	GE/U
E. Thompson*	LMSC
W. Berger	Ford

5. Test Method-Internal Visual (and Others)

D. Laptiz**	TRW
E. Cormier*	GD/C
C. Murphy	RI

6. MFG Certification

C. Murphy**	RI
S. Caruso*	NASA/M
M. Gaudiano	NASA/J

7. Packages (and Substrates)

L. Schneider**	TRW/MM
P. Eisenberg*	Northrop
E. Cormier	GD/C

Schedule (Hybrid Microelectronics Committee)

April 4 and 5	First meeting of committee
April 5	Initial meetings of subcommittees
April 7 - June 18	Subcommittee activity
June 19, 20, and 21	Second meeting of committee

**Chairperson
*Vice-Chairperson

IMPLEMENTATION OF THE COMMANDER'S POLICY SUPPLIER SURVEILLANCE

Warren Geller
Staff Engineer
Lockheed Missiles & Space Co. Inc.

- Electronic part complexity increased
- Part specification improved
- New SAMSO policy to manage electronic parts procurement
- LMSC support to SAMSO

Electronic Part Complexity has Increased

Part Type	Complexity
Resistor	Basic part
Transistor	2 diodes
Microcircuits:	
SSI	Up to 12 gates (48 transistors)
MSI	12-100 gates (400 transistors)
LSI	100-2000 gates (8000 transistors)

Specification Complexity has Increased

MIL-S-19500 — Transistors and Diodes

JAN, JAN TX, JAN TXV, Class S — MIL-STD-750

MIL-M-38510 — Microcircuits

Class B & C, Class A, Class S — MIL-STD-883

Hybrids

Specifications under development

New SAMSO Policy - Supplier Surveillance

Technique to improve management of electronic parts for space use

Recognizes need for field personnel involvement

MIL-STD-1546 Appendix B (proposed)

Supplier Surveillance Functions

- Provide real-time support to the supplier
- Interpret specification (subjective requirements)
- Direct failure analysis and corrective action
- Control part configuration
- Recommend specification improvements
- Manage discrepant hardware
- Identify and correct problems at the earliest point

Monitored Line Service

LMSC arrangement with AF to provide surveillance (monitoring) for Government contractors

Plan and parts list available

LMSC History in Surveillance

Monitored line parts program - 5 years

Prepared 200 drawings and specifications for transistors and IC's

Delivered 170,000 parts to:

15 major LMSC programs
20 subcontractors

Program continuing and evolving to Class S

Observed effectiveness - cost/performance

SAMSO COMMANDER'S POLICY - SUPPLIER SURVEILLANCE

BOX LEVEL TEST FAILURES (ONE PROGRAM)

- PARTS PURCHASED IN SAME TIME FRAME
- PARTS TESTED IN SAME EQUIPMENT

	QUANTITY PARTS	NUMBER FAILURES	% FAILURES	RELIABILITY GAIN FACTOR
DIGITAL IC'S				
MONITORED	22,537	32	.14	8X
NON-MONITORED	556	6	1.1	
LINEAR IC'S				
MONITORED	5,270	2	.04	15X
NON-MONITORED	1,877	11	.59	
HYBRID IC'S				
MONITORED	535	8	1.5	.6X
NON-MONITORED	654	6	.9	
TRANSISTORS				
MONITORED	17,459	0	.0058	8X (ASSUMING 1 MLP FAILURE)
NON-MONITORED	2,064	1	.047	

Summary

Electronic part complexity approaching equipment level

Part specifications undergoing continual upgrading

Surveillance policy developed to better manage modern part procurement

LMSC history verifies effectiveness of surveillance

Monitored line service available to contractors

The subject of today's workshop, Microelectronics/Hybrids, represents the state-of-the-art in electronic devices. As the complexity of SAMSO missions increases, the use of these devices will become a practical necessity. A major problem facing us is converting the design requirements

for these new devices into reliable, space-worthy hardware.

The Commander of SAMSO has recognized that what today we are calling a "part," yesterday we called an electronic box. He suggests that we must begin to extend some of the management techniques previously reserved for electronic equipments to the manufacture and testing of these complex parts.

The technique developed for the advanced management of electronic parts, called "line monitoring" or "supplier surveillance" has been described in a new SAMSO policy. The requirements for supplier surveillance, to be imposed contractually at a future date, are defined in a recently released draft of Appendix B to MIL-STD-1546, titled, "Supplier Surveillance." For the past 5 years LMSC has been managing the Monitored Line Parts Program, performing the supplier surveillance function described in Appendix B. Having delivered over 170,000 transistors and integrated circuits to 15 LMSC major programs and over 20 LMSC subcontractors, it was considered appropriate that we share our experience with SAMSO and its contractors.

The need for surveillance derives from the complexity and depth of requirements found in recent semiconductor specifications. We have exceeded the point where thicker specifications can affect the reliability of our hardware unless we supplement the specifications with personal attention. In addition to providing real-time support to the supplier in specification interpretation, on-site personnel are needed to direct failure analysis and corrective action, to manage hardware not complying with the letter of the specification but useful to the user, and to provide a direct communication line between the users and the manufacturing and testing personnel. The objective is to manage parts with paper and people.

LMSC experience has revealed that the monitoring team must contain 3 segments: 1) resident monitoring personnel; 2) centralized technical and administrative support; and 3) supplier participants. The resident personnel includes a quality engineer supported by one or more inspectors and a parts engineer to provide technical direction. This group is fully capable of managing the routine tasks of inspecting, testing, and shipping products. The central group provides in-depth technical support when problems occur, prepares specifications and drawings and completes the communication line to the users. It must be recognized early that the system cannot function unless the monitoring team is adequately supported by supplier personnel. They must willingly be members of the team.

User specifications and drawings are normally not used in the supplier's assembly and test areas in preference to their own documentation. Again, recognizing the complexity of modern part requirements, it becomes critical that a careful review be made of supplier procedures and specifications to verify that hardware is being manufactured and tested in accordance with user requirements.

The LMSC Monitored Line Program has proven to be extremely successful. The failure rate in equipment has been approximately 0.1 percent and the causes of two-thirds of these failures have since been the subject of corrective action. Only one failure has occurred at a testing level higher than box final test. There have been no failures at system level testing or in end use. Cost and schedules have been improved by the low rate of failures.

Recently, the SAMSO Launch Vehicle Programs authorized use of LMSC Monitored Line parts in their Systems. A detailed plan has been prepared for making a Monitored Line Service available to government agencies and their contractors. A contract is currently under negotiation to implement this plan for the use of SAMSO.

COORDINATED PROCUREMENT FOR IUS

Wilber L. Barker
Manager, Central Material
Boeing Aerospace Company

Objectives

- More effective coordination and interface with parts supplier(s)
- Reduce the proliferation of program component specifications
- Establish the most cost effective approach for total program requirements
- Better application of current procurement techniques

Anticipated Advantages

- Reduce number of specifications required
- More effective use of personnel, i.e., engineering, quality assurance, purchasing
- Lot test charge savings
- Improvement in total program scheduling through program allocation of parts
- Maximize importance of program requirements to participating manufacturers
- Establish the most economical unit prices

Areas of Concern

- How are requirements identified and consolidated?
- How are parts shortages handled when manufacturer cannot meet total program needs?
- Spec preparation, negotiation, changes
- How are parts ordered by the participating buyers?
- Prime contractor liability
- Pricing of requirements

Parts Management/Parts Control Board

- Identification of part candidates
- Selection of device prime
- Optional participation

Responsibilities of Device Prime

- Specification coordination
- Configuration baseline
- Schedule
- Source inspection
    - Radiographs
    - SEM photos
    - Lot test data
- Discrepant parts disposition
- Coordinated procurement proposal
    - Parts price
    - Data price
    - Purchase contract placement window
    - Shipment dates
- Price negotiation
    - Total quantity
    - Lot charges

Participating Buyer Responsibilities

- Purchase contract
- Requirement changes
- Specification change coordination
- Review test data
- Accept/reject parts

Liability Disclaimer

It is agreed the device prime will have no liability for part deficiencies, part delivery slides or other concerns related to coordinated procurement. The subcontractor's sole recourse, if needed, shall be through its contractual relationship with the parts supplier.

Conclusions

- Objectives will be met
    - More effective coordination with suppliers
    - Reduce specification proliferation
    - Establish most cost effective approach
    - Improve procurement technique

Recommendations

- Adopt coordinated procurement for custom specification parts
- Preserve participating subcontractor responsibility

WORKSHOP SUMMARY

LSI/HYBRID WORKSHOP
PROPOSED CONCLUSIONS AND RECOMMENDATIONS

Note: Workshop attendees are asked to indicate either agreement or disagreement with each of the conclusions and recommendations listed by writing the word AGREE or DISAGREE in the adjacent left-hand margin. Additional comments, conclusions or recommendations are encouraged and should be written in at the end of this listing.

CMOS/SOS RELIABILITY STATUS

Conclusions:

1. The CMOS/SOS technology has made significant advances during the past two years, and it is in production status at RCA and can be qualified for applications in space.
2. CMOS/SOS is the leading technology for VLSI functions as a result of its outstanding speed power product and high packing density.
3. CMOS/SOS devices have demonstrated long-term stability at 25 DGR. C.
4. Mask compatible second sourcing is available.
5. RCA is fully committed to supplying space qualified CMOS/SOS parts.

Recommendations:

The aerospace industry should be making more use of CMOS/SOS technology.

I^2L/LSI IN MILITARY APPLICATIONS

Conclusions:

1. I^2L is a viable LSI technology for military and space applications.
2. I^2L can meet temperature and radiation hardness requirements for space applications.
3. I^2L gate arrays will permit low volume, fast turnaround LSI implementation.
4. I^2L failure rates of less than 10 FITS under normal stress are predicted.
5. Advanced I^2L has growth potential for VLSI ($\geq$50 MHz, $\geq 10^4$ gates per chip).

Recommendations:

1. Provide incentives for LSI/VLSI utilization in space systems.
2. Encourage set-up of systems oriented custom LSI centers with qualified low volume fabrication facilities.
3. Encourage development of LSI technologies with high degree of fabrication commonality to assure second sourcing.
4. Establish procurement policies to guarantee life-cycle support for LSI parts.
5. Develop user-oriented LSI performance and reliability test procedures and specifications.

RADIATION EFFECTS ON LSI

Conclusions:

The two critical LSI problems are:

1. The evolution of high performance arrays at the expense of internal design margins on critical parameters which leads to increased radiation vulnerability. If this trend continues, all hardened LSI will have to be custom structures significantly different than main-line industrial technology.
2. Experimental evaluation of the worst-case radiation failure level. Displacement effects, ionization effects and electrical overstress must be determined by a set of bias conditions and post-irradiation test vectors that can cost-effectively reflect the unique failure mechanisms and worst-case failure level. This is, however, almost straightforward compared to detecting the worst-case logic upset level from a pulsed ionizing radiation exposure.

Recommendations:

1. SAMSO must get involved with the development of "essentially industrial" LSI technology with radiation hardness as a substantial but not dominating concern. Technology support should be implemented in all high-performance/high density LSI technologies (including n-MOS, CCD, CMOS/SOS, digital I^2L, and combined bipolar analog/digital I^2L). The level of support must be of sufficient magnitude and focus to get and retain the attention of the US semiconductor industry.
2. The LSI test problem should be formulated as a program/goal-oriented set of tasks that can be examined in detail. These might include:
   a. A methodology to define a set of test vectors to establish worst-case bias conditions on an MOS/LSI array (CMOS, CMOS/SOS or n-MOS) during ionizing radiation exposure;
   b. Extensions of LSI test methodology to identify the location of a failed cell and the nature of the radiation-induced failure;
   c. Development of an optimum set of test vectors to detect transient logic upset resulting from pulsed ionizing radiation exposure.

3. Test methodologies should be developed for application by system designers rather than the semiconductor LSI designs. Maximum use must be made of post-fabrication performance parameters with minimum dependence on design or fabrication parameters.

HI REL APPLICATIONS OF CUSTOM LSI

Conclusions:

1. Custom LSI is applicable to high reliability systems.
2. The design development should be done by the user based on available IC technology.

Recommendations:

1. Base designs on well characterized standard cells.
2. Make extensive use of computer aids to keep the design cost down and maximize confidence in the design.

DESIGN TOOLS FOR CUSTOM LSI

Conclusions:

The use of custom CMOS LSI parts (along with microprocessors and memories) is the most reliable and cost-effective way to implement space systems.

Recommendations:

1. Special attention is needed to provide for custom LSI part design early in the prototype and testing phase of programs so that the life cycle cost benefits from the use of LSI parts can be achieved during the production phase of the program.
2. Custom LSI parts should be qualified on a family basis through testing of standard cell libraries and universal array vehicles rather than by fully qualifying each custom part individually.

TESTING MICROPROCESSORS

Conclusions:

1. Test patterns derived through both logic and functional simulation offers the highest confidence test for space and high-rel applications.
2. The use of both techniques is not practical for all applications due to cost considerations and limited access to the correct schematic (that is, unless the pattern derived through logic simulation is provided by the device manufacturer).
3. The best single method for space application is functional simulation.

MICROPROCESSOR SLASH SHEET DEVELOPMENT

Conclusions:

1. Complete characterization testing must be accomplished before a specification can be written. Even then, significant problems exist in defining certain specification details (e.g., dynamic burn-in circuit, accelerated life test conditions, V_{ZAP} tests, capacitance tests, etc.).
2. The device has several serious limitations (e.g., lack of test ability, timing problems, problems in running functional tests rated frequency, etc.).
3. The ability to perform functional and switching tests is seriously limited on several test systems and even on different configurations of the same test system.
4. No LSI can be expected to meet all the requirements of MIL-M-38510, Class S, as they now exist.

Recommendations:

Because of all the subtle, and not so subtle, problems encountered in characterizing and specifying microprocessors, there is need for a single clearing house to collect, analyze, and disseminate LSI information.

CLASS S LSI PLANS

Conclusions:

Existing Class S microcircuit requirements are inadequate for LSI.

Recommendations:

Expand Class S requirements for LSI to include:

1. Design review
2. Built-in testability
3. Certification of design rules, cell libraries and CAD
4. The use of reliability test devices in wafer lot acceptance

HI REL HYBRID MANUFACTURING CONSIDERATIONS

Conclusions:

There is a spittle contamination problem which effects hybrids or any large area device.

Recommendations:

Operators, inspectors and others coming in close proximity of open hybrids should wear face masks.

CLASS S HYBRID CIRCUIT COMMITTEE

Conclusions and Recommendations:

The increased use of hybrid microelectronics in SAMSO systems is inevitable, SAMSO must take active steps to assure compatibility of hybrid usage with space reliability and performance requirements, and SAMSO/NASA/RADC should develop improved specifications and standards for space quality hybrids.

IMPLEMENTING COMMANDER'S POLICY FOR SUPPLIER SURVEILLANCE

Conclusions:

The management techniques formerly reserved for equipment procurements must be applied to complex electronic parts such as LSI.

Recommendations:

The SAMSO Commander's Policy as implemented in proposed Appendix B of MIL-STD-1546 should be given immediate attention.

COORDINATED PROCUREMENT FOR ISU

Conclusions:

Objectives will be met:

1. More effective coordination with suppliers
2. Reduce specification proliferation
3. Establish most cost effective approach
4. Improve procurement technique

Recommendations:

1. Adopt coordinated procurement for custom specification parts.
2. Preserve participating subcontractor responsibility

WORKSHOP SUMMARY

- Emphasis on LSI and hybrids
- Fifteen presentations with discussion
- Tabulation of conclusions/recommendations commented on by participants
- Final wrap up discussion
- Major problems identified in
  - LSI technology
  - Custom LSI
  - LSI test and specification

LSI TECHNOLOGY

Problem:

- No single LSI technology has demonstrated ability to meet all SAMSO requirements
- Apparent growing divergence between standard LSI circuit capability and SAMSO requirements

Solution:

- SAMSO must continue to support and evaluate multiple LSI technologies
- SAMSO must influence the design of certain standard LSI circuits

CUSTOM LSI

Problem:

- Custom LSI circuits offer significant advantages however limited production precludes adequate characterization
- Custom LSI circuit design and development cost and schedules could be prohibitive

Solution:

- Base custom designs on well characterized computerized design systems and associated technologies
- SAMSO should establish approved custom LSI design systems/contractors

LSI TEST AND SPECIFICATION

Problem:

- Standard LSI circuits, particularly microprocessors are extremely difficult to test
- Existing Class S microcircuit requirements are not adequate for LSI

Solution:

- Support and expand evaluation and characterization of LSI
- Establish a single clearing house to collect, analyze and disseminate LSI information
- Expand Class S requirements to include LSI

OTHER OBSERVATIONS

- SAMSO should promote the effective use of LSI
- Class S LSI requirements urgently needed
- Future space systems will employ more complex hybrids

- Line monitoring concept applicable to hybrids and LSI
- LSI and complex hybrid circuit specification and procurement more similar to subsystem than part
- May be counter productive to dictate technology

WORKSHOP G
MISSION ASSURANCE AND MANUFACTURING

Co-Chairmen

Col. William R. Shaffer, Director
Inertial Upper Stage Project
USAF, SAMSO

Mr. Lee Gray, Director
Quality Assurance
Space Div., Rockwell International

Workshop Coordinators

Mr. Paul Burdeno, SAMSO/PMGQ
Mr. Pete Dirnbach, Rockwell International

AGENDA

Wednesday, April 26

0830-0840	Welcoming Remarks	Col William R. Shaffer, SAMSO
0840-0910	Critical Item Control-Lessons from Space Shuttle	Mr. Lee B. Gray, Rockwell
0910-0935	Tailoring for RDT&E	Mr. Richard Flohr, Lockheed
0935-1000	Workmanshop Standards and Practices	Mr. Leonard Katzin, Aerospace
1000-1025	The AFCMD Contractor Management System Evaluation Program	Mr. Edward E. Mazzanti, AFPRO-TRW
1025-1100	Break	
1100-1125	The DLA Contractor Assessment Program	Mr. Spencer Hutchins, DCASR-LA
1125-1150	Engineering Review of Mfg & Insp Instructions	Mr. Edward L. Caustin, Rockwell
1150-1220	Production for Space and its Assoc Problems	Mr. John P. Flanagan, Honeywell
1220-1225	Description of Afternoon Session	Col. William R. Shaffer, SAMSO
1225-1330	Lunch	
1330	Roundtable Discussions	

Discussion Moderators:

Mr. Albert W. Fry,	SAMSO/ICBM
Mr. Leonard J. Romanick,	AVCO Systems
Mr. Stanley B. Chamberlain,	General Dynamics – Convair
Mr. Spencer Hutchins,	DCASR – LA
Mr. Edward E. Mazzanti,	AFPRO – TRW
Mr. John Grosvenor,	TRW
Maj. Willie Collins,	SAMSO
Mr. Michael R. Butler,	McDonnell Douglas

CRITICAL ITEM CONTROL

Lee B. Gray
Division Director Assurance Management
Rockwell International

The government and the contractor are both always concerned that they may be working "very accurately on the wrong problem." In these days of severely limited budgets, we must quickly zero in on the real potential problems and assure that we are controlling that hardware that can cause loss of life or mission or both.

In recent meetings between top Air Force officials and company executives, the quality assurance function has justly been criticized for lack of innovation. We make damn sure it is built like the print, even if the print is wrong. Quality audits conducted by the government and industry often result in satisfactory reports only to have a major failure occur a short time thereafter. Their usual response is, "It's a design problem." If this is true, then their quality audit should have found this "design" problem.

In order to control "critical items," we first must define the term. In the Shuttle program, an item is critical if its failure could lead to loss of life, or mission, or its redundant items cannot be checked out prior to flight, or the loss of the redundant item is not detectable in flight, or lastly, all redundancy can be lost by a single credible event. On the Shuttle Orbiter program, two percent of the items we build at Space Division and 49 percent of the items we buy fall into at least one of the above categories.

The Failure Mode and Effect Analysis (FMEA) identifies the items which are summarized in the Critical Items List (CIL). Let's walk through an actual case of how an assessment was made of one small critical item in a review recently held to assess the readiness of our Orbiter for its maiden space flight.

The Orbiter's payload bay doors must be opened on orbit each flight in order to perform its mission. These doors cover the 60' by 15' payload bay (Figure 1). These doors are operated by a complex mechanical drive and latch mechanism. Prior to entry, at the conclusion of the mission, these doors must close. Failure to do so would cause mission and crew loss. One item which could cause this condition is the torque shaft power drive. The CIL states that the cause of this failure could be stress corrosion, fatigue or overstress due to binding. All of these potential causes must be investigated but we will only follow the last cause, "overstress due to binding." (Figure 2.)

The Quality Engineer (QE) must then gather all of the specifications and drawings concerning this power drive. He develops a drawing and specification tree until he gets down to the component whose failure would be the cause identified in the CIL. The QE must then prepare a questionnaire regarding this critical item and its unique failure mode. Note that there is no standard questionnaire or audit check list. Each must be customized if you are serious about getting to the real problem. (Figure 3.) The QE then has a questionnaire review session with the responsible design and reliability engineers. After incorporating their comments, he is ready to hit the road to do a product assessment. This in-house preparation time has taken from six to ten days depending on product complexity.

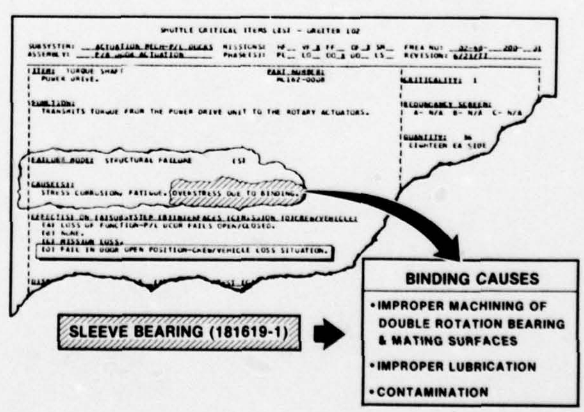
At the subcontractor he will average three to five days of product assessment (one half the time spent in-house). He spends his time on the floor looking at the hardware and the shop paper that is producing it, not Q.A. plans and procedures. He is asking, "What did you do?", not "What were you supposed to do?" Our QE discovers that the sleeve bearing is only being lubricated on the outer diameter but not on the inner diameter. This is according to print! In that the failure of this and similar bearings in the payload bay door system could cause loss of crew and mission, it is obvious both inner and outer diameter should be lubricated. This means change the print! A normal quality audit would have found the process OK in that it met the print.

When the QE returns from his assessment, he briefs the directors of quality and reliability and makes any recommendations for corrective action. Those actions deemed necessary to verify that the failure mode cannot be built into the hardware are then implemented with the supplier.

This product assessment process responds to the criticism of top military and industry executives. The assessor (auditor) must be an "expert" in the product to be assessed. I have been audited by auditors that wouldn't recognize my product if they fell over it in the hall! The product assessment method becomes a "rifle shot" technique rather than the "shotgun" technique which results from the standard audit questionnaire. It means an increased preparation time, but less time at the supplier.

It is a cost effective method in that you are no longer working "the wrong problem very accurately." You are now solving the "real problem" before it occurs in flight.

FAILURE CAUSE ASSIGNMENT



QUESTIONAIRE DEVELOPMENT

SLEEVE BEARING (181619-1) ➡ **FAILURE CAUSE: BINDING**

SAMPLE QUESTIONS & ANSWERS

Q- HOW IS DUAL ROTATION OF BEARING ASSURED?
A- BY MACHINING BEARING FOR WORST CASE TOLERANCE OF 0.0005

Q- DOES INSTALLATION PROCEDURE SPECIFY LUBE ON OUTSIDE DIAMETER OF BEARING AND INSIDE DIAMETER OF HOUSING?
A- *NO, ONLY INSIDE DIAMETER OF HOUSING IS LUBRICATED* *

Q- HOW IS BEARING CLEANED TO PREVENT CONTAMINATION?
A- PARTS ARE CLEANED TO 300 LEVEL & ASSEMBLED IN 100,000 CLEAN ROOM

NOTE: ALL OF THE ABOVE OPERATIONS ARE VERIFIED BY QUALITY CONTROL

*AS A RESULT OF THE CONCERN FOR INSUFFICIENT LUBRICATION, PROCEDURE WAS CHANGED TO ADD REQUIREMENT FOR LUBRICATION OF OUTSIDE DIAMETER OF BEARING

TAILORING THE QA ROLE FOR RDT&E

Richard H. Flohr
Manager, SSD Product Assurance
Lockheed MSC

My presentation today begins with the Quality role as applied in the LMSC Space Systems Division (SSD) for development programs. I have, for the purpose of this presentation, assumed that MIL-Q-9858A would be the basic contractual specification imposed on our "development" product.

MIL-Q-9858A requires:

- The establishment of a quality program by the contractor to assure compliance with the requirements of the contract.

- The Quality program shall be subject to review by the Government Representative — and is subject to the disapproval of the Government Representative whenever the contractors' procedures do not accomplish their objectives.

We must, therefore, be responsive to MIL-Q- and any other contractual quality specification in response to RFPs because the danger of nonresponsiveness and possible disqualification in the source evaluation process. Let's face it, this is a strong deterrent to contractor ingenuity.

If both the Customer and the Contractor agree, and I'm sure we do, that tailoring specifications to the particular needs of a given program is cost effective, then tailoring should be accomplished. When it should be accomplished, by who, when, and how is important. We believe the quality specifications should be tailored by the Customer and made a part of the RFP. We further believe that the RFP should also encourage additional suggestions for tailoring by the contractor without fear (real or imagined) of being found nonresponsive. After contract award, contract incentives should be given for continued tailoring through change proposals or some other means.

The Contractor should have the option to respond to an RFP with a detailed explanation of the methods by which he plans to carry out the specified requirements. The mechanism for this is the preparation of a "Program Plan." We recommend that "Plans" be required, approved and made contractual by the customer, and thereafter used as the basis for judging contractual compliance.

Engineering Hardware Phase

The purpose of quality assurance during research and development (engineering and prototype hardware) is to enhance product acceptability and to prepare for product acceptance. This is basically accomplished through quality assurance participation in design reviews and through quality assurance planning for subsequent flight hardware procurement and production.

The essential role of Product Assurance in the design process is to ensure inspectability and testability. We believe this can best be accomplished in the program area by an integrated team comprised of Program Office, Engineering, Manufacturing, Product Assurance and involved support functions.

We believe we should be a "help-mate" to Engineering during the engineering/prototype hardware production phase by assisting "as required." It must be stressed, however, that the hardware in this phase is not intended to be used as a deliverable flight item or for testing of flight hardware. Our main emphasis is workmanship inspection as opposed to Corrective Action. Discrepancy documentation and corrective action should be without AFQA or DCAS participation.

Flight Hardware Phase

When the Program evolves from the Engineering hardware phase to qualification/flight hardware, Q.A. involvement must be expanded. During the Design phase, Product Assurance and Manufacturing should sign the design review package at both PDR and CDR and all subsequent changes.

We believe that the quality requirements we impose on suppliers should be tailored. For example, the requirements imposed on ho-hum procurements would be different than for "critical" items. Every attempt is made to use our Supplier's existing quality system and procedures to eliminate the necessity for him to "re-invent" the wheel to comply with our standards. Perhaps we can forego having the supplier prepare a special Q.A. Program Plan if a standard plan is available and if it is adequate.

Perhaps the major phase is in the in-house manufacturing and assembly activity. We feel all production work must be performed under controlled conditions to Engineering requirements using Manufacturing Work Instructions (Shop Orders, etc.) as controls.

Another major effort is "Test and Delivery." Product Assurance must ensure that final inspection and test of completed items are performed to give an overall measure of each item's conformance to end product specification requirements.

It must be stressed that a vigorous program to detect the real cause of all failures must be pursued so that corrective action can be taken to prevent recurrence of similar discrepant conditions if only on other similar programs.

In conclusion, I believe for this type of program that MIL-Q-9858A should be invoked but that certain features should be tailored out; for example, Cost of Quality.

Deviation from the "norm" can be expensive and possibly counterproductive.

WORKMANSHIP IMPROVEMENT AND STANDARDIZATION

Presented by L. Katzin
The Aerospace Corp.

As an attempt at improving and standardizing workmanship levels of operator performance on high reliability programs several suggestions were made:

1. A workmanship manual be prepared by a government agency. This manual should provide contractually imposed standards of workmanship quality. It should not be limited to just soldering, but should cover all standard workmanship items associated with high reliability types of electronic manufacturing.

2. Schools, established by a government agency, should train and certify both government and industry instructors. These classes should include both the theory behind quality judgments and the practice and training of performing quality. The workmanship manual previously addressed could be used as part of the tutorial text material.

3. Certified operator training programs, using instructors that have been certified by the government schools, be established at various government and industry locations. These programs would select candidates who qualify for high reliability work based on dexterity, aptitude and other psycho technical testing and then teach them. Not all taking the course need necessarily pass it. Those who do pass should be accredited and periodically re-accredited. Graduates of these programs would qualify for operator or inspector classifications and certification.

4. Continuing grading should be established for operators and inspectors. This grading would be a contractual commitment that evaluates the quality performance of each individual based on actual rejections by inspection and quality department verifications of inspection thoroughness.

With the above four items implemented, the level of workmanship quality should improve and should approach a single standard of excellence for all of the high reliability electronics industry.

THE AFCMD CONTRACTOR MANAGEMENT SYSTEM EVALUATION PROGRAM

Edward E. Mazzanti
Chief, Quality Assurance Division
AFPRO/TRW

This portion of the workshop concerns government in-plant involvement at contractor's facilities. The purpose of this briefing is to give you some insight as to what this involvement entails for those contractors under the cognizance of AFCMD – The Air Force Contract Management Division. Most of our involvement centers around our Contractor Management System Evaluation Program, or CMSEP, and that is the subject of my briefing today.

Why CMSEP? Well, the answer is very simple. Our old techniques were considered ineffective. In the late 60's and early 70's, a series of surveys were conducted at various contractors facilities. Time and again the same deficiencies in contractor operations were reported. During the same period some serious hardware deficiencies on major Air Force programs were noted and this caused some serious concern throughout AFCMD. So it was determined that a new approach was needed. Something that would emphasize prevention of system deficiencies that could in turn cause hardware defects. It had to be conducted within available AFCMD resources - which meant that we had to change our way of doing business and redirect our efforts toward prevention and it was decided the way to do it was through evaluation of Management Systems.

This concept is based on the principle that product quality is the direct result of management quality. It is also based on the assumption that a responsible contractor dedicated to the delivery of a quality product within cost and schedule will develop management systems in an orderly and planned manner. It then makes sense that we in AFCMD expend a major portion of our efforts toward ensuring the existence and operation of adequate contractor management system.

In the fall of 1973, under the direction of General Nunn, the AFCMD Contractor Management System Evaluation Program was established. Management System Indicators (MSIs) were developed as the primary component of the program and these are used for guiding Air Force Plan Representative Offices (AFPROs) evaluation of management systems.

Under the program, each functional area of an AFPRO is responsible for full evaluation of its contractor counterpart organization.

Command Management is the responsibility of the Air Force Plant Representative and he must ensure evaluation of his counterpart who is the contractor's chief operating official.

There are a number of MSIs assigned to each functional area and each is a question directed at a discrete portion of the contractor's management system addressed by the functional area.

The MSIs provide an evaluation approach that will address all levels of management within a contractor's organization. The Command Management MSIs (CM-1 & 2) were developed to ensure that the AFPR verifies that the contractor's chief operating official has properly documented his objectives and policies and his assignments of authority and responsibilities to top executive and functional managers. The first MSI in each of the other functional areas provides an evaluation similar to CM 1 & 2 except it is conducted at a lower level in the organization. For example: The first MSI from Quality Assurance which is designated as QA-1 will be used by the AFPRO Quality Assurance Division Chief to ensure that his contractor's counterpart, the functional manager of Quality Assurance, has properly stated his policies and assignments of authority and responsibilities to fulfill his function. Finally, all other MSIs are used to determine the degree of implementation of authority and responsibilities at lower levels of management in all areas.

For example, one of the 15 MSIs for Quality Assurance, QA-3, addresses that portion of the contractor's Quality Assurance Management System that concerns work instructions. One of the 9 for Manufacturing Operation, PD-9, addresses that portion of the contractor's manufacturing management system that concerns packaging, handling and transportability.

The MSI's are rather broad and don't really lend themselves to a detailed evaluation – but they're not intended to.

Instead, there are a series of Condition Questions assigned to each MSI. These are probing questions that assist an evaluator in investigating the status of an element of the area covered by the MSI. There are twelve Condition Questions that address the 2 MSIs for Command Management – 92 for the 15 MSIs for Quality Assurance and so on. Typically QA-3, the MSI dealing with work instructions, contains five condition questions.

As you can see, these questions are more specific and this is where the evaluations are, in fact, conducted. With that, let's take a look at the evaluation process.

This process is actually a test for existence, adequacy and compliance. Existence of contractor procedures that address the management system in question. The next step, is to determine if the procedures adequately meet all requirements or standards. And finally, the compliance check verifies that the contractor is in fact complying with his own procedures.

To assist in this evaluation process, further criteria are developed for each Condition Question. There are Assessment Criteria which are questions or short statements developed to test existence and adequacy of the documented system. Assessment Criteria are developed from such sources as MIL-STDs, ASPR clauses, regulations, industry handbooks or other documents describing various features of an acceptable management system.

Compliance Criteria are also developed which relate directly to Condition Questions and these are extracted from the Contractor's Written Procedures and are used to determine if the contractor personnel are complying with their own documented requirements.

THE DLA CONTRACTOR ASSESSMENT PROGRAM

Spencer Hutchens
Dep. Dir., Quality Assurance Directorate
DCASR – LA

The Contractor Assessment Program, within the Department of Defense is a program to reduce involvement of Government personnel in the day-to-day operations of selected contractors, while, at the same time, assuring that quality of product is maintained. The paper reviews development of the program since its conception by the DoD Quality Assurance Council in early 1975. By 1976, the detailed implementation plan developed by Defense Logistics Agency had been approved and a test program initiated.

Contractor eligibility criteria are discussed. These include the requisite that the contractor be a DoD prime contractor, with MIL-Q-9858A requirements and that the item in question shall have been in continuous production for a reasonable period of time. Additionally, the contractors' quality management must be considered capable of continuing to maintain quality production, the contractors' pre-award and post-award history must be good, there should be no major quality deficiencies and one or less Materiel Deficiency Report issued per million dollars shipped of product shipped, among other criteria.

Contractors initially proposed by the DCAS Regions for inclusion in the program are screened and evaluated by a Contractor Assessment Advisory Board, a sub-committee of the DoD Quality Assurance Council. Subsequent to this review, coordination with the buying agencies is effected. An agreement covering the contractors' participation in the program – on a volutary basis and with no increase in his costs – is signed. The Government develops a Quality Assurance plan tailored to the specific situation at each contractors' plant.

The Phase I Trial Program, initiated in late !976, included RCA and Bendix. One product line at Texas Instruments subsequently was added. Cleveland Pneumatic was selected for participation in early 1978.

Evaluation of the Phase I Trial Program was encouraging, and indicated that objectives of the program were being met with no degradation of product quality. Under a Phase II Test Program, developed in early 1978, six companies are being considered for inclusion.

ENGINEERING REVIEW AND APPROVAL OF WORK INSTRUCTIONS

Edward L. Caustin
Division Director, Q&RA
Rockwell International/LAD

To assure mission success, it is necessary that the Manufacturing and Inspection instructions faithfully reproduce the Engineering design. Engineering review and approval of those work instructions has been found to be a good technique to help assure the effectiveness of the work instructions. Let me summarize: The critical areas or operations required for mission success must be identified. The associated work instructions must be specific, not general, and Engineering should review and approve the critical work instructions to verify that they will reproduce what Engineering designed.

Work instructions are those documents that are used by Manufacturing, Inspection, and the Test groups to build and test a product. It is with these work instructions that the Engineering design is converted from paper to hardware or operating software. Questions usually arise: Does the end product faithfully represent Engineering's designs? Did the Manufacturing, Inspection, and Test operations create the product as directed by the Engineering design? To eliminate these questions, the work effort must be well defined. "What is critical" must be identified; "when to inspect" must be determined; "how to inspect" must be specified; as well as determining "which test" should be run. This is the dilemma that Manufacturing, Inspection, and Test groups face. Without Engineering's help, mission success is surely put in doubt. The engineer knows more about what is critical with his designs than the other functions could possibly know – the other functions' expertise, however, knows "how to inspect," "how to test," and can determine "when to inspect" and "when to test." But to determine "what is critical" and how it affects the mission, is best done by Engineering.

Let me take you briefly through an example of such a requirement that was critical in order to assure mission success. Engineering played the basic key role. A recent contract requirement required the vehicle to be designed using fracture mechanics criteria. Parts that were considered fracture critical had to be designed to withstand initial flaw size of 0.050" depth, located in the most critical portion of that part for the total life of the vehicle without becoming critical. Engineering identified, on the drawings, which parts were fracture critical. They also identified the critical areas on each of those parts and the direction of the critical stresses. This information allowed Quality Assurance to identify the proper inspection processes to be used. The Inspection requirements document was also specified on the drawing. Hence, by the drawing specifying the various critical aspects of the part and calling out the Inspection requirements, the inspector is led to the Specific Inspection Instruction by part number and, consequently, to the Inspection Instruction how-to's to do the job properly. It was through this technique we were able to get the high reliability necessary to employ fracture critical design using a small, critical flaw size. Each of these Inspection Instructions are processed through Engineering for approval. Review by Engineering provides a check and balance on the work instruction system. It makes sure that the instructions cover the critical items to assure mission success, and it also helps insure that the build and inspection sequence is realistic. When we had the engineer's approval, we knew we had understood his design.

A major benefit that occurred by having Engineering involved in the work instruction, was their obtaining a better appreciation of the needs of Quality Assurance and the value of Quality Assurance's inputs to the design process. Engineering now understands Inspection's needs and readily accepts our comments on their design. Many designs, at Engineering's request, are now reviewed by Quality Assurance in order to assure that the part to be fabricated is inspectable. With the processes that are available today, parts can be designed and built that cannot be reliably inspected – a sure way of not insuring mission success. Another side benefit is the fact that it forces another look at the design. By ridding designs and work instructions of error early in the program cycle, more attention can be given to properly reproducing the products and, hence, assure mission success.

In summary, I would like to again point out that the critical areas for mission success must be identified. The work instructions must be specific to the needs and not general. To assure that they all create the proper product, Engineering must review and approve those work instructions.

PRODUCTION FOR SPACE AND ITS ASSOCIATED PROBLEMS

John P. Flanagan
Production Section Manager
Honeywell Inc.

The American assault on space began in the late 1950's. Success came for Explorer 1 on January 31, 1958, when a 70 foot tall Jupiter Rocket succeeded in putting a 30 pound payload into orbit. This was the beginning of our space age. Since then the space program has seen some failures but many, many successes. The 360 foot Saturn 5 put a 200,000 pound sky lab into orbit and pushed manned spacecraft to the moon. The Mercury, Gemini and Apollo manned flight programs were the ultimate in well publicized success.

But, this publicized success has hidden from public view the problems that have plagued the manufacturers of space hardware. With the early restrictions of available booster power came constraints on weight, power and precious volume. These constraints led to cramming more and more piece parts and circuitry onto the valuable real estate of printed circuit boards. The boards themselves became 20 or more layers to accommodate all of the required interconnections. This has led to miniaturization of piece parts and the problems with handling such minute items during the assembly process. Today's plated wire memories have 2 mil wires which are inserted into 4 mil tunnels and soldered to landing pads which are on 10 mil centers. Just as state-of-the-art advancements are being made in hardware design, so too must production methods and processes be improved. Microscopes of higher and higher power are now employed just to be able to see what one is doing. More and better lighting and lenses are being employed for assembly and for inspection. Gloves and finger cots are commonplace annoyances for Production personnel. Operators working with static sensitive parts must wear special smocks and grounded wrist straps, and work on special tabletops.

The problem of heat dissipation has taken a few new twists. Forced air cooling is becoming a thing of the past giving way to conductive dissipation of heat through use of thermal overlays. The overlay further complicates the process of soldering piece parts to circuit boards. The soldering operation must be perfectly executed at the bottom of a "well." The use of aluminum foil wrapped around stiff bars for further heat dissipation is another engineering innovation which the assembly operators would rather not have.

The use of computer controlled automatic test equipment which minimizes dependence on human operators is becoming more and more a requirement. Diagnostic software which pinpoints failures is a necessity. This is necessary, as the environment to which the hardware is subjected in flight must be more than matched during the test process. Operation over temperatures from -85°F to +200°F are not unique. Vibration, shock, vacuum, salt water spray, 100% relative humidity, dust and accelerations are environments that the hardware must survive.

Survivability is a by-word in our industry. Some hardware must survive the radiation effects from a nuclear explosion or from passing through the Van Allen radiation belt and it still must perform its intended mission flawlessly. The Viking Lander, went through a "cooking process" at 233°F for 156 hours in order to sterilize this earth built hardware so that the planet Mars would not be contaminated by the earthman's visit and mission performance. The spacecraft must survive and the planet must survive.

As we reap more benefits from space missions, we generate demands for more missions. Our boosters have become more powerful, and yet the payloads have become even more sophisticated. With sophistication comes higher cost and as the payload becomes more expensive, the need to assure mission success becomes more of a requirement. The ultimate in payload sophistication, of course, is man himself. It was man in space who applied the fix to the crippled sky lab. However, many of these sophisticated payloads form the backbone of our nation's defense capability. To many, this is by far the most important reason that demands flawless, successful mission performance regardless of cost or hardship. To improve the probability of mission success, we have upgraded our piece parts and established parts reliability requirements unheard of a decade ago. We require that parts be traceable from cradle to grave. Certified parts must be installed by certified operators with certified instructions and certified equipment. This has created data collection systems, piece part and paperwork traceability systems and configuration identification systems that only the technology of modern computers can handle.

This leads me to the most consistent of the manufacturer's problems – that of soaring costs. We, in manufacturing, must constantly strive to reduce costs while complying with all of the requirements for reliability and at the same time, meeting the proposed delivery schedule. We are under pressure to utilize more sophisticated equipment in the manufacturing process to hold or reduce the cost line, while at the same time we are told to reduce energy consumption. Rework to correct cosmetic blemishes possibly deteriorates rather than enhances the reliability of the product. We must constantly strive not to lose sight of the fact that equipment performance rather than beauty is the prime requisite.

Different agencies may procure the booster, the guidance system, the computer, the payload experiments, etc., for the same mission. Each agency's particular parts specification is interpreted by each prime contractor, is interpreted again by all of the sub-contractors, and results in the parts vendor having many different requirements imposed on him for the same basic part for one mission. Standardization of parts specifications for all Government Procuring Agencies would go far to help reduce parts costs and delivery schedules, and relative at least one source of the manufacturer's problems.

The end result of our frustrations and hard work is the reward to our pride when missions are successful. We always want to identify with success. We dread the consequences of our hardware failure on our nation's position at the world's peace tables, and even more so, on the human payload that some missions require. Who will ever forget the plight of Apollo 13 when its April 1970 rendezvous with the moon was aborted due to a spacecraft accident. The whole world was caught up in the emotions of the moment as the lives of those three astronauts

depended upon their remaining equipment functioning outside of the capacity for which it was initially intended. No space hardware supplier wants such an awesome spectre to haunt him because of failure of his product. Instead, we will do anything to overcome the problems and hardships. We will work within all constraints while trying to use logic and reason to remove those which we are convinced are unreasonable. Whatever it takes, MISSION SUCCESS is our committment. Our reputations demand it; our paychecks depend on it; our survival requires it.

WORKSHOP SUMMARY

WORKSHOP SUMMARY

SYNOPSIS OF ROUND TABLE DISCUSSIONS

1. Critical Item Control:

- Problem

Resources allocated to monitoring critical item control are spread too thin.

Cause

Contractural Requirements, e.g., MIL-STD-1543, define critical items too broadly.

Reommendation

Revise MIL-STD-1543 to categorize critical items by potential effect on Mission Success.

Action

SAMSO/Industry Team

- Problem

Quality Management has failed to take full advantage of available analytical techniques, e.g., FMEA and System Safety analysis in the planning and conduct of audits, reviews and inspection.

Cause

Lack of Management attention or emphasis.

Recommendation

Make Management at all levels aware of potential benefits of using these techniques.

Action

Industry

2. Establishing Realistic QA/Mfg Requirements:

- Problem

Establishing realistic QA/Mfg Requirements for R&D and low volume programs.

Cause

Blanket imposition of specifications.

Recommendations

Encourage realistic tailoring by SPO. Encourage use of contractor prepared plans to tailor requirements. (Acceptable to Government CAO & SPO) (Place on contract)

Action

SAMSO

3. Workmanship Standards and Practices

- Problem

Lack of workmanship standardization within the industry.

Cause

NO organized direction by Government or industry.

Recommendations

Government contract for identifying and preparing minimum workmanship acceptance criteria – OR – Professional society (i.e.,: AIA, ASQC, etc.) to recommend and prepare minimum workmanship acceptance criteria.

Action

Government or Industry Association.

- Problem

Implementation of workmanship standards for "Hi-Rel" applications.

Causes

Cost. – Resistance to change. – lack of top management involvement.

Recommendation

Specific contractural imposition of standards.

Action

Government

- Problem

Operator/Inspector training for "HI-Rel". parts fabrication.

Cause

Cost. – Lack of standard requirements. – No organized direction by Government or industry.

Recommendations

Workmanship incentive at operator level. – Establish universal training requirements. – Indoctrination of top management to cost effectiveness of improved training.

Action

Industry.

4. Government/Industry Mission Assurance Interface:

- Problems

Poor tailoring of contract requirements. – Inconsistent/unrealistic letters of delegation. Insufficient coordination between SPO, CAO and contractor QA.

Cause

Lack of qualified QA personnel at Buying Offices (SPO)

Recommendation

Establish a program for assuring qualified QA personnel are assigned to SPO's

Action

SAMSO

5. Transition From Design to Manufacturing:

- Problem

Mission critical areas do not receive appropriate attention.

Cause

Existing "critical item" clauses require listings of critical items without sufficient follow-thru, e.g., identification on engineering drawings.

Recommendation

RFP should specifically require that critical characteristics be identified on engineering drawings.

Action

SAMSO/Industry Team

- Problem

Work instructions may not cite acceptance. — Criteria for critical items due to lack of involvement by design engineering.

Cause

Lack of design engineering involvement in development of work instructions.

Recommendation

Press for review and sign-off on work. — Instructions by design engineering on all critical items.

Action

Industry.

6. Problems of Low Volume Production:

- Problem

High cost and schedule impacts are associated with low volume production.

Causes

Low volume precludes economies such as lot or batch build. — Fixed costs exist regardless of quantity being produced. — Proprietary processes at vendors or long lead items frequently cause program delays.

Recommendations

Encourage innovation by incentive clauses. — Tailor existing MGMT/Production Systems (DWG. Release, detailed work instruction etc.) for small programs. — Assure schedule realism at time of RFQ by Government. — Buy proprietary process rights to avoid schedule impact.

Action

SAMSO/Industry

- Problem

Lack of viable supplier response to low volume procurements.

Cause

Too many MIL-SPEC requirements for suppliers to be bothered with. Too much investment for small amount of profit.

Recommendations

Overbuy parts and screen in-house. — Establish method of tailoring MIL-SPECS for imposition on suppliers, which avoids waiver/deviation methods.

Action

Industry.

- Problem

Electrical connectors are plagued with chronic quality and schedule problems.

Cause

Unknown

Recommendation

An industry or Government organization or Select Committee should examine this issue.

Action

Government or Industry.

WORKSHOP H

OPTIMIZATION OF TESTING OF COMPONENTS, SUBSYSTEMS AND SYSTEMS FOR MISSION ASSURANCE

Co-Chairmen

Lt. Col. Duane Baker
Chief, Test & Evaluation Br.
SAMSO/AWST

Mr. Martin L. Adams
Director, Systems Effectiveness
GPS System, Rockwell
North American Space Operations

Workshop Coordinator

Mr. Thomas Martin
SAMSO/PMGQ

AGENDA

Wednesday, April 26

0830-0845	Welcome, Procedural and Administrative Announcements	Mr. Martin L. Adams, RI Space Division
0845-0905	Status and Future Plans MIL-STD-1540A	Lt. Col. Duane Baker, SAMSO/AW
0905-0925	Implementing MIL-STD-1540A – The GPS Experience	Mr. Martin L. Adams, RI Space Division
0925-0945	Interface Testing Considerations	Mr. Nick G. Babich, Boeing
0945-1015	Break	
1015-1035	Role of Development Testing in Component/Systems Level Test Program	Mr. Dean L. Lindstrum, Hughes Aircraft Co.
1035-1055	Improving Test Effectiveness	Mr. Bernard J. O'Brien, TRW Space Systems
1055-1200	Divide into Subgroups	
1200-1300	Lunch	
1300-1600	Workshop Subgroup Sessions	
1600-1630	Group Review/Summarization of Findings	Group Leaders
1630	Summary	

MIL-STD-1540, TEST REQUIREMENTS FOR SPACE VEHICLES STATUS AND FUTURE PLANS (SYNOPSIS)

Lt. Col. Duane Baker
SAMSO/AWST

An effective test and evaluation program is a mandatory requirement to assure mission success of our military spacecraft. To emphasize the need for adequate testing, examples of system failures are discussed which may have been prevented by more effective testing.

Due to the unique characteristics of these systems, a special Military Standard was developed to address the testing required to effectively simulate the expected environment and uncover deficiencies before the systems are put into operation. MIL-STD-1540A was issued in 1974 and considerable experience has been gained with the use of this document. In this discussion the current requirements in MIL-STD-1540A are outlined with some of the background and rationale behind these requirements. Experience has shown some deficient areas. These are discussed along with current plans for revising the document.

IMPLEMENTING 1540 ON GPS (SYNOPSIS)

Mr. Martin L. Adams
RI Space Div.
Mgr. Systems Effectiveness
Rockwell International/DS

GPS was the first satellite program to have MIL-STD 1540 fully imposed. Experts wrote the MIL-SPEC but non-experts must make its implementation a practical reality. Although GPS is considered by SAMSO to have achieved the highest level of compliance, it still took over 70 meetings of the Test Criteria Review Board, 150 waivers and X test criteria changes notices. This means we struggled to change or accepted some degree of non-compliance – What changes and why.

1) Sequence Changes

   Acceptance and qual environments were run consecutively. Should we have run the full ATP, then gone into qual?

2) Tolerances

   Many waivers were approved because we couldn't hold the ± 3 db amplitude for power spectral density during vibration. Should 1540 be revised to 6 db?

3) Burn-in

   Literal compliance w/1540 will cause 37.5 temp. cycles on a box with an $85^{o}C$ temp. swing to achieve the required 300 hours of burn-in. Test time during environments is expensive. Is this requirement necessary?

4) Equitable Retest

   Were you ever asked to perform a repeat of test sequences which you thought were unreasonable, after you had a failure? What checklist could you prepare to decide an equitable retest, after failure or interruption?

INTERFACE TESTING CONSIDERATION (SYNOPSIS)

Mr. Nick G. Babich
The Boeing Co.

Testing of interfaces, both on the subsystem and system level, has always been a primary discipline in the sequence of verifying functional compatibility of booster and payload/spacecraft systems. Many sources of documentation, Mil Std 1540A included, try to define a logical, thorough set of test requirements that will assure compatible systems and minimize the risks associated with high technology, often state-of-the-art, designs. However, the effectiveness of Mil Std's and other test documentation can be significantly influenced by the programmatic test philosophy existing at the time of application. The often-used cliche, "Test what you fly and fly what you test" may be a "test goal" but often ends up, due to physical and/or practical reality, only partially attainable. Thus, in order to obtain a thorough "wringing out" of all interface parameters, a total system concept must be kept in the forefront.

Some considerations for discussion, to reevaluate current interface testing practices and focus attention on those checks and balances needed to assure successful operational performance of the payload/spacecraft systems, should include the following:

Use of a total Systematic Approach

1. Payload/Spacecraft Systems to Booster Systems (AVE, GSE, TSE).
2. Consideration of <u>ALL</u> System Interfaces (Electrical, Mechanical, Structural, Envelope, Nuclear).

Use of MIL STD Requirements vs. ICD Parameters

1. Test to verify compliance with Mil Std's or ICD's?
2. Testing to first active element or beyond?

Optimization of Test vs. Analysis

1. Design philosophy of interface system simulators.
2. Need for retest after completion of final design.
3. Need for interface verification on each flight unit.

Test Scheduling

1. Implementation of a Building Block Concept.

ROLE OF DEVELOPMENT TESTING IN COMPONENT/SYSTEM LEVEL TEST PROGRAM (SYNOPSIS)

Mr. Dean L. Lindstrom
Hughes Aircraft Co.

1) Schedule Allocation for Development Testing

Most space programs produce so few flight or development models that they seldom reach full design maturity. To accelerate this process, development testing needs to include test designed to uncover weaknesses as well as to develop capability. Unfortunately, this part of development testing is often over-looked. The designer hardly has time to develop the design, much less find its problems. This may be as much his fault for not taking time to plan as it is the Program Manager's for not allowing time to plan. Time should be scheduled for problem prevention, as it is for problem correction.

2) Simulation of On-orbit Operation

It is clear that many failures occur on orbit because that is the first time that mode was tested. Better simulation of operational modes is one answer, but can be expensive. However, even simulation of operational conditions is not adequate to eliminate failures that are time and stress dependent. More important than operational simulation is the application of sufficient stress to accelerate those failures which can occur in unique operational modes and under time and stress conditions. The test program should be planned so that development, qualification, and acceptance tests at component and system level are adequate to uncover failure modes and eliminate potential failures under operational conditions.

3) Failure and Test Data Analysis and Feedback

Each company has different strengths and weaknesses. Setting up test programs to answer everyone's weaknesses is very expensive. A key to optimizing your test program is to assess the problems which you have had. Then design a test program to prevent those problems.

IMPROVING TEST EFFECTIVENESS (SYNOPSIS)

Mr. Bernard J. O'Brien
TRW Space Systems

This discussion takes a critical look at some of the considerations which influence the planning, implementation, analysis - and hence the overall effectiveness of component and system - level testing for space systems. It includes a discussion of constraints placed on innovation and flexibility, and looks at some measurements of screening effectiveness.

WORKSHOP SUMMARY

WORKSHOP SUMMARY

TEST WORKSHOP RECOMMENDATIONS AND CONCLUSIONS

Test Workshop

We were fortunate in having many distinguished people from both Government and Industry in our test workshop. There were four PHD's in the group and, from some of the ideas surfaced, I suspect there were a few more lurking in the background unannounced. We began our workshop with a series of short presentations to orient, motivate and provide background information to the participants. Col Baker gave a short talk on the status of MIL-STD-1540 (MIL-STD-1540A, Test Requirements for Space Vehicles). We talked a little about the practical implementations of MIL-STD-1540A on our GPS Satellite Program. Mr. Nick Babich from Boeing gave us an overview of Interface Testing experience. Mr. Dean Lindstrom of Hughes gave an interesting review of the impact of development testing on the component and system level test program. Finally, Mr. B. J. O'Brien of TRW Systems gave us some good insight on the practical matters of improving test effectiveness. These speakers really succeeded in getting the attention and arousing the interest of the group. Some very good dialogue developed in the process. There were a few more participants than expected; however, our workshop was well balanced among Air Force, NASA, Aerospace Corporation and Industry representatives; fifty-one in all. We enjoyed excellent dialogue with surprising empathy, understanding and appreciation for problems considered and improvements suggested. A significant part of our effort centered about MIL-STD-1540A; therefore, at the onset I would like to express a personal opinion. Having implemented MIL-STD-1540A on the GPS Program, I think it is good document. It needs improvement, but on balance, if its implementation is approached in a reasonable and rational manner, it is not nearly as scarey as some people think it is.

Discussion Areas

We broke down into seven groups or discussion areas as listed. Originally we had eight subjects preselected. We ended up combining several of the old ones with a couple of new ones. One new topic involved "Flying Qualification Hardware," while another treated the impact of the Space Shuttle on test programming. Coverage of these subjects was greatly enhanced by NASA participants; our thanks for their help, support and contribution.

Development Testing

In the area of Development Testing there was a concensus that greater attention to Development Test Planning is needed. Moreover, improved planning must be accompanied by greater discipline in the accumulation, application and implementation of development test data. One recommendation suggested an independent review of test planning to assure balance between the design and practical test viewpoint. Development testing tends to be dominated by the design operation. Another recommendation suggested use of development testing to learn the weakness of the design early to either correct or control. Postulation of non-standard events or conditions may be very beneficial in learning the weak link early enough to characterize and control or remove it. Finally, better salesmanship and cost analysis in the test area was suggested in order to determine where the best test investment is. The general feeling expressed by the group pointed to a greater return on test investment "Up Front" where characteristics and capabilities are determined and accommodated as opposed to the matter of follow-on individual compliance demonstration testing.

Test Planning

The Test Planning Group considered the areas of schedule and test changes. There was a feeling among Government members that the Government should be open to contingency planning. This is another way of saying we need more schedule realism. In a competitive environment everyone is optimistic and schedules are generally success oriented. We like to think and project in terms of success; however, experience teaches otherwise. Excessive test optimism can be a disservice to everyone and in the long run produces events compression and test exigencies which tends to degrade mission assurance. Test scheduling and planning should be reconciled with experience. If you see no failure, be suspicious, be aware and be perceptive; go back and examine that test. The other area of consideration centered about test changes. Beware of readily accepting a test solution for a prior failure problem. Each failure has its own character and conditions. Be sure you have considered and identified the source of the problem, confirmed the test solution and have positive reason for test change.

Test Standards

The area of test standards brought out some interesting views on the analysis of the sequence and ordering of qualification and acceptance tests. The present practice of acceptance level testing to establish performance base for qualification test, followed by acceptance test to demonstrate survival and performance was judged to be an inefficient use of test facilities. The possibility of establishing the initial operational test status of the test item under qualification levels would effectively combine tests and in many instances improve the efficiency and economy of test with no impact on mission assurance. The recommendation to permit this option was advanced to enhance the effectiveness and economy of test programming and utilization of test facilities. Another consideration involved system level thermal-vacuum testing. Testing under vacuum can be very expensive when running thermal cycling. It was recommended that an option be provided for running the thermal cycling at ambient pressure providing you have run both hot and cold soak tests under vacuum. Additionally, it was suggested this approach might be more perceptive because of the added confidence in having achieved and stabilized at the temperature extremes.

The subject of Burn-in testing was hotly debated. The current requirement of MIL-STD-1540 is 300 hours. The subject continues to be controversial in a gross sense primarily because of insufficient data to establish where we are in terms of optimum Burn-in time for the items under test. This subject was

recommended for further study. Another area identified for further study is the sequence of shock and vibration testing. It was suggested that the sequence of vibration followed by shock, which is the sequence usually encountered during launch, might not be the most perceptive in discovering problems. It was suggested that shock followed by vibration would be a more meaningful test sequence in terms of mission assurance. It was recommended this area be examined to determine if sequence change will enhance mission assurance.

Fly What You Qualify

NASA Goddard has seven years experience with what they call the "Protoflight" concept. Simply stated it means "Fly What You Qualify." It is an interesting concept worthy of further evaluation. Flight history data and test to maximum predicted flight environment plus a 3 DB margin proved successful. There is risk of overstressing components and it is prudent to approach the possibilities cautiously. Be careful about levels. Present Air Force policy for Space Flight is to completely refurbish qualification test items prior to space flight readiness certification. The Fly What You Qualify concept offers some interesting possibilities for simplification in the process of flight certification of qualification hardware. Further discussion was centered about the Space Shuttle impact on testing. We are lacking specific data on environments and shuttle peculiarities. However, we are provided an opportunity for the first time to conduct on-orbit, pre-deployment test and checkout. We must use this added advantage wisely and avoid undue relaxation or elimination of ground testing in light of on-orbit capabilities and recovery option. A low earth orbit launch complex offers some interesting challenges to effective and economical testing of space vehicles.

Test Problems and Equitable Retest

This discussion related primarily to MIL-STD-1540 and the sometimes unpleasant but very real considerations relating to test problems and equitable retest. There is need to strengthen the retest criteria presently included in MIL-STD-1540. At present almost every retest is a negotiated solution. The type and extent of retesting, particularly following rework, needs further consideration and the development of a discipline pattern within MIL-STD-1540.

Discussion then shifted to the issue of test planning and its role in the design review process. Testing is not something that occurs automatically. It must be addressed with the same rigor as the basic design and must reflect a consistent and compatible interface with the design. It must be planned and disciplined and still remain sufficiently flexible to accommodate historical variables without sacrifice to the effective and economical achievement of all test objectives. This mandates early and intensive test planning and review effort. It was suggested that an independent evaluation of test planning in the early stages of the design process would add value to the test planning and test programming efforts and products.

The next topic discussed involved the matter of Stored Space Vehicles. Time se[illegible] to create failures in storage notwithstanding [illegible] most diligent preparation and implementation o[illegible] storage discipline. The possibility of time/temperature dependent mechanisms working and other subtle aspects of time storage impact, prompted the feeling among participants that source re-test is necessary after six months of storage. While there were some special factors to be considered, it was generally agreed that a functional verification test under ambient conditions would suffice, providing that critical environmentally activated conditions/events were properly checked. The type and extent of Re-Test and the extent of environmental conditions required is dependent on analysis and characterization of the item under consideration. MIL-STD-1540 should provide for Re-Test considerations appropriate for stored vehicles.

Interface Testing

The matter of interface testing and specific requirements relating to the interface tend to be neglected. There is need to consider functional interactions and reactive variables as well as fit and form prior to the point where correction becomes an expensive and time consuming proposition. There is need for additional treatment of Interface Test Criteria and requirement in MIL-STD-1540 to assure early consideration of functional as well as physical compatibility across interfaces.

Test Data generation and evaluation was then considered by the group. It was a general consensus that too much reliance is placed on gross test results without sufficient attention to variations within the tolerance bands. Analysis to determine significance of signs relating to test instability (trends within acceptable tolerance limits) can be of value in characterization and identification of incipient failures. Often we complete a test successfully with only a cursory review of data. We tend to ignore data from successful tests, we concentrate on failure. The group recommends review of critical parameter test data for anomalous indications and analysis to determine probable cause and significance even though the test was successful Look at Successful Test Data. It was suggested that the establishment of minimum standards for data review should be developed and applied.

In closing, it has been said that if a single idea comes out of this conference, it has been well worthwhile. I agree with that statement; however, even if no new ideas were developed, the free exchange of ideas and dialogue between government and industry still make it all worthwhile.

DISCUSSION AREAS

- Development Testing
- Test Planning
- Test Standards
- Flying Qualification Hardware
- Shuttle
- Test Problems & Equitable Retest
- Interface Testing

DEVELOPMENT TESTING

- Greater attention to dev. test planning needed
- Govt could lead in assuring adequate schedule & discipline
- Need an independent review of test planning (test viewpoint vs. design)
- Off-Limits testing at dev. may be very beneficial

  Postulate some non-std events - e.g. Power Interrupt, Very low voltage drop, transient, etc. Learn the weak link early.
- Better cost analysis of testing would help show where the best test investment is. We suspect more up-front is more cost effective.

TEST PLANNING

- Schedule

  Govt. mgmt should be open to contingency scheduling for failures & retest. AF INPUT!

  Need more schedule realism - beware excess optimism when justifying schedule, reconcile with failure experience if there were no failures. Re-examine test.
- Test Change

  Beware readily accepting a test solution for a prior failure problem.

  Make sure there is a reason to change.

TEST STANDARDS – RECOMMENDED CHANGES TO MIL STD 1540

- Environmental acceptance & qualification testing (components)
  - Permit option of accept & qual, each env. in turn, as alternative to complete ATP followed by complete qual. program
  - Rationale – Practicality . . .
- System Thermal Vacuum Acceptance Testing
  - Permit option of thermal cycling at ambient provided hot & cold soaks under TV also conducted
  - Rationale – Problem in reaching accept temps on components in many space veh. designs.

RECOMMENDED FOR FURTHER STUDY

- Burn-In-Testing

  Industry experience on burn-in failures be researched to establish a realistic and sufficient duration for burn-in (now 300 hours)
- Sequence of Testing – Shock & Vibration

  Shock – Then vib – Perceptive sequence
  Vib – then shock – usual system sequence

FLY WHAT YOU QUALIFY

- NASA Goddard has 7 years experience w/"Protoflight" concept
- Flight history equiv. to separate qual. hdw.
- Risk of overstressing components – be careful about levels.
- SAMSO should consider this concept

SHUTTLE IMPACT

- We lack data on environments
- Beware excess relaxation of grd. Test due to on-orbit pre-deployment check ability.

TEST PROBLEMS & EQUITABLE RETEST

- Retest guidelines in 1540 could be strengthened for component retest
- For space vehicle testing – every retest is really a negotiated solution
- Multiple retests following rework need exploration and possible treatment in 1540
- Test planning should be addressed at PDR to the same rigor as the design
- Stored Space Vehicles
  - Time seems to create some failure mechanisms
  - Storage 6 mos. requires some retest
  - Non-environmental functional verification is probably adequate
  - Extent of test & possible environments depends on complexity of space vehicle
  - Consideration for test of stored vehicles should be incorporated into MIL-STD-1540

INTERFACE TESTING

- Interface testing (specific requirements) tend to be neglected
- Early treatment needed
  Consider functional interactions, not just physical
- Some treatment in MIL-STD-1540 is desired

TEST DATA

- Data from "successful tests" often ignored
- Examine "Good" data for trends within the acceptable boundaries
- Some minimum STANDARDS for data review would help

WORKSHOP I

INDUSTRY'S APPROACH TO PERSONNEL MOTIVATION AND TRAINING AND SAMSO/AEROSPACE/INDUSTRY EXPERIENCE SHARING

Co-Chairmen

Mr. Allan Boardman
Director Navigation & Sensor
Systems Subdivision
The Aerospace Corporation

Dr. Stuart O. Parsons
Director, Human Relations
Lockheed SSD

AGENDA

Wednesday, April 26

0830-0840	Introduction	Mr. Allan Boardman, Aerospace
0840-0905	Motivation — The LMSC Motivation Programs	Mr. Stuart O. Parsons, Lockheed, LMSC
0905-0930	Q.C. Circles	Mr. William E. Courtright, Hughes
0930-0955	Parts Supplier Personnel Effectiveness Programs	Dr. Gerald R. Pieters, Signetics Corporation
0955-1020	Subcontractor Motivation — CARE — GD Convair	Mr. Wesley E. Magnuson, General Dynamics
1020-1040	Coffee Break	
1040-1105	Motivation Programs at Boeing Aerospace	Mr. Gene Peretti, Boeing
1105-1130	Training Programs at Honeywell	Mr. Dave Stevenson, Honeywell Inc.
1130-1155	PA Training Program at Aerospace	Mr. Allan J. Boardman, Aerospace
1155-1220	Experience Sharing — SAMSO/ Aerospace/Ind.	Mr. Jim Teresi, Aerospace
1220-1330	Lunch (No Host)	
1330-1630	Open Discussion	
1630-1700	Discussion Summary	
1700	Prepare Workshop Summary/ Recommendations	

A Closer Look at Lockheed's Motivation Programs

Dr. Stuart O. Parsons

Key Words: Motivation, Productivity, Employee Participation, Quality of Work

Abstract

A short description and tabular information are provided for five Lockheed employee centered motivation programs which contribute to increased productivity, cost savings, and hardware quality. Eight lessons learned are reviewed to aid other organizations in developing programs which will be the most effective in assuring mission success and in increasing the quality of work. It is concluded that such motivational programs can increase productivity, improve employee attitudes, reduce defects and accidents, and assure high probability of mission success. However, these activities require strong management commitment including budget, time, support personnel and active follow-up.

Introduction

Industrial motivation and training are traditionally thought of in terms of awards, management goals, financial incentives and formal courses. However, it can easily be demonstrated that this is a systems problem, not unlike complex hardware, involving technology and structure as well as people. Most organizations have evolved from product or functional requirements, from the attempt to impose traditional pyramid structures, or from the idiosyncracies of executives. The requirements and needs of all the people in the organization are rarely considered in such organizational decisions. Back in 1763, Adam Smith in his book, The Wealth of Nations, emphasized the point that people are motivated by self interest. Unfortunately we often forget this fact in the evolution of our organizations and the structuring of our motivation programs.

Motivation Programs

At Lockheed Missiles and Space Co., (LMSC) in Sunnyvale, California we have recently attempted to utilize the principles of greater employee participation and involvement, reduced arbitrary controls and increased organizational linking in a number of programs including:

Quality Control (QC) Circles.

A employee participation program started in Japan involving the training of workers in quality engineering techniques and then applying these techniques in weekly meetings on a voluntary, but paid basis, to analyze and solve quality and production problems.

TEAM

Employees meeting with their supervisor and a facilitator for one hour a week for 8-12 weeks to discuss work impediments and explore potential solutions. Multi-level meetings are held monthly to bring the most difficult problems to the attention of other organizations and higher management.

Upward Communications

Skip-level meetings between 10-16 randomly selected salaried employees and their respective Vice-President. Each employee brings one positive and one negative aspect of the job to the meeting. These are posted, discussed and actions designated.

Upward Performance Evaluation

A voluntary program whereby a manager or supervisor can be evaluated by his subordinates on fifteen variables. He is privately counseled on the results which include the profiles of his own evaluation vs. the mean values of his subordinates' ratings.

Potential Damage Evaluation

Employees at all levels who are familiar with an operation, evaluate the potential for damage to hardware or injury to personnel on a three point scale for each subfunction in the process. This sensitizes the employees to safety and provides management with a prioritized list for eliminating potential hazards.

All of these programs are directly related to creating and maintaining products of the highest level of quality and thus are of interest to attendees of a Mission Assurance Conference. Figure 1 presents a summary of important parameters related to these programs. More details on the mechanics, training and outcomes of these efforts may be obtained from the articles listed in the first four references at the end of the paper or from direct inquiries to the author.

Lessons Learned

It is felt that the remainder of this paper can most beneficially be devoted to lessons learned over the past ten years since a company or government jurisdiction would probably wish to tailor an internal motivation program to their own requirements and environment.

Nothing Lasts Forever

All motivation and training programs such as Zero Defects, Extra Care, or Q.C. Circles become somewhat 'old hat' and tend to lose their impact after 3-4 years. The less structured the program the greater the potential for a longer life. However, the best technique is to either put a time limit on the program at the outset or modify the format and schedule after an extended period.

Management Values and Involvement

There must be complete program acceptance and active participation by all members of management from the Chairman of the Board down to first level supervisors. If such programs receive only perfunctory lip service or tacit approval from company executives, they are doomed to failure from the out-

Figure 1 Recent Lockheed Motivation Programs

Name	Period	Participants	Frequency	Measures of Effectiveness
Q.C. Circles	1973 - Present	310 Manufacturers on Trident Missile	Weekly Meetings	o Cost Benefit Ratio of 6:1 o 90% of Participants Feel Program Effective o Reduction in Defects per Man Hour Worked
TEAM	1969 - 1974	3200 Hourly & Salaried Mfg, PA, Eng, Programs, Procurement, etc.	Weekly Meeting 8-12 Weeks	o 77% Problems Resolved o Attitude Surveys - TEAM Groups Signif. Higher than Controls o Multimillion Dollars Savings
Upward Communications	1972 - Present	785 Salaried Employees - All Organizations	1 per Month	o 60% Problems Resolved o 89% of Participants Rated Program as Beneficial
Upward Performance Evaluation	1973 - 1977	850 Employee Raters, 70 Mgr/Supv, Ratees	10-20 per Year	o Subjective Evaluations from Employees and Managers - Very Positive
Potential Damage Evaluations	1970 - Present	Approx 30 Employees per Study plus 1 Full Time Human Engineer	Approx 1 per Year	o Reduced Rework, Rejects & Accidents o Improved Employee Attitudes o Better Methods of Fabrication & Assembly

set. Our most successful efforts at LMSC have occurred when Directors and Vice Presidents have attended meetings and employee presentations, or have established their own groups from members of their immediate staff. It is also important to bring all power structures/decision makers together in support of a motivation program. For example, an advisory group representing the customer, company and union should be established. If we could point to one mistake which has been most detrimental in our TEAM, Upward Communications, and QC Circle efforts it would be the structuring of programs which didn't actively involve middle management on a regular basis. This produces communication channels between first line personnel and executive level management with mid-management feeling left out of lacking control over information transfer. Unless people in an organization feel extremely secure, this practice can produce fear and covert retaliation by 'old guard' line managers.

The Shoemaker Knows Shoes Best

We have been consistently amazed and impressed by the high calibre and technical depth of processes, techniques, and new innovations which have been formulated by working fabricators, assemblers, technicians, and engineers in group meetings and in individual interviews. One of the most frequent concerns exhibited in Upward Communications meetings involves management or the customer not requesting technical information directly from the expert when a problem exists on a spacecraft or when a presentation is made. When will the Air Force Captain and industry Senior Engineer be permitted to solve the problem on a pin-puller design at their level rather than trying to resolve this technical problem at the General/Vice President level?

Real vs Stated Costs

This is a double edged problem. On one hand we find that stated costs frequently don't include the time of supervision and other indirect personnel, training materials, employees time in meetings and resolving problems, or program evaluation exercises. On the other hand, workers who are 'turned on' by their jobs and the opportunity to exhibit some creativity or decision making may be 10-30% more productive. One company found that, when they reduced the number of hours from 40 to 36 (with a commensurate reduction in pay) rather than laying people off during a downturn in sales, the employees were more dedicated and actually produced at a higher rate than before. In summary, true system costs should be computed on a total input vs total output basis rather than on partial program costs or a single cost improvement.

Evaluation - Necessary But Simple

It is highly desirable to continually audit and evaluate motivation programs. In fact, the initial evaluation procedure should be developed concurrently and as an integral part of the Program Plan. Management will demand some criteria of effectiveness to justify the program costs. However, cost saving estimates, grievances before and after, work-rework times, discrepancy rates, attitude survey, etc should be kept simple. Our experience has shown that most Quality Assurance or Finance data collection methods are not applicable for this purpose and are far too detailed. Also, the formal Cost Improvement Program requires too much paper work and administrative approval levels to be worth-while. On one program we found that 75% of the support time was spent in developing cost improvement data. A good rule of thumb is to not exceed 10% of the total program cost or time on evaluation.

Programs Don't Run Themselves

The most common misconception is that once a motivation program is planned and started in the line organization, it will perpetuate itself on a continuous basis - like a breeder reactor. Unfortunately, at least during the first few years of a program, facilitators are needed. On TEAM and Q.C. Circles we found that a good ratio was 1 facilitator for every 4-6 groups. Their functions are to schedule meetings, obtain equipment and facilities, help keep meetings on the objectives, counsel with the leader and group members, obtain outside experts, coordinate with other groups, and aid in follow-up activities. These facilitators have to understand the technology, the company organization and dynamics, and human behavior.

Secondary Benefits

Although we have directed the discussion of motivation programs toward the improvement of Mission Assurance through increased human and hardware reliability, there are a number of important secondary benefits from such efforts including:

Supervisory Development. On-the-job-training in listening and dealing with employees and obtaining counseling and feedback from the facilitator.

Productivity. The removal of impediments to getting the job done and giving people a larger 'piece of the action' are fundamental factors in increasing productivity.

Opening Up Communications. Once people see that management is receptive to changes and new ideas, vertical and horizontal communications will improve dramatically.

Integrate Management and Employee Goals. In analyzing and researching possible solutions to problems, employees gain a better insight into the constraints and forces with which management must contend. Experience showed, that after investigating working procedures and methods, TEAM groups would recommend that about 25% of these systems be left intact because they represented the most effective alternative. Regarding increased management insight to employee goals, in an Upward Communications meeting one of our Vice Presidents was asked, "Have you heard anything in this meeting which your were completely unaware of?" After thinking about it for a minute he responded, "No, but I certainly got a different slant on some of these problems when I heard them described by you people on a face-to-face basis."

Must Become Lifestyle

In the view of the author, when considering long term future organizational trends (10-20 years hence) motivation programs as described in this paper may be viewed in the future as merely crutches or interim measures in the evolution of more

productive and socially responsive organizations. Perhaps, the day has already arrived for eliminating or modifying such rigid structured programs as Zero Defects, Extra Care, Cost Improvement Quotas, etc. Companies such as Donnelly Mirrors, Hewlett Packard and Tektronix, who have evolved company wide profit sharing and participative management practices over the years, are probably not good candidates for such programs as TEAM or Q.C. Circles since they have already achieved a type of corporate self-actualization.

Unfortunately, most of the large aerospace companies historically were conceived during the period when autocratic methods were taken for granted. Also, their customer has traditionally been the Department of Defense or other like government agencies; and therefore, they have tended to be structured and to operate in a paramilitary style. We see significant changes occurring at Lockheed and other similar companies. An example of this is an internally distributed book which was written by Dr. Derald Stuart, Vice President and General Manager of LMSC's Missile Systems Division. In the book (Ref. 5) Dr. Stuart writes, "I am a strong supporter of the concept of management by negotiated objectives - and I firmly believe that the methods of accomplishment of objectives are critical. The end results do not always justify the means used. Hence, I try to generate and support an environment and moral climate that allows all to be proud to be part of the organization. I believe that one of management's most important tasks is to protect the future and that can best be done by developing and depending upon strong (competent) people. Hence, I try to generate and encourage the personal development and growth of all members of the organization. I believe I can summarize the above by saying that I foster building dedicated (product and program oriented) teams and finding win-win solutions. I continually push for and encourage activities, policies and actions that allow everyone to be proud of what he's doing - thus allow them to have 'fun' rather than just 'do a job.' Participative management, management by objectives, management (team) development, quality circles, etc., are all ways of letting the doers 'have fun' and 'do their own thing' to the organization's benefit - instead of them 'just working'." From personal experience the author can state that Derald 'practices what he preaches.' With executives and managers of this stature we can hopefully look forward to both a higher quality of work and a higher quality of life in the future.

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Biography

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Quality Circles at Hughes Aircraft

William E. Courtright

Key Words: Quality Circles, Hughes, motivational, cost effective

Abstract

The success of quality circles at Hughes Aircraft Company supports the goals of this SAMSO MISSION ASSURANCE PROGRAM. For example, the Hughes Quality Circles approach helps to overcome the present counter productive communications and motivational practices and it establishes a new cost effective method that helps solve problems and assure mission success.

Introduction

In early 1976, the Hughes Aircraft Company became aware of the progress that the Lockheed Missile and Space Company was making with their Quality Circle Program. A trip was made to Lockheed's Missile Systems Division at Sunnyvale, California in order to get a firsthand look at their QC Circle Motivation Program. Shortly thereafter Hughes researched all available literature on participative motivation programs including a detailed review of the Japanese QC Circle material under J.U.S.E., Joint Union of Science and Engineers. With this combined information on motivation programs, Hughes developed a Quality Circle Program and started a pilot run in September 1976 at the Hughes Carlsbad, California plant, the location of the Industrial Products Division.

Implementation of the Quality Circle Program at Hughes

Pilot Program at Carlsbad

The pilot Quality Circle approach included briefing the general manager as well as other top management at Carlsbad on all aspects of the program and receiving their approval for proceeding with the program. All other concerned management and employees were trained at the end of 1976 and four Quality Circles were started in January 1977.

Expansion into Industrial Electronics Group and Other Hughes Groups and Divisions

The Carlsbad Quality Circle program was so successful as a pilot program that it was expanded in June 1977 to four other divisions in the Industrial Electronics Group. These four other divisions included the Connecting Devices Division at Irvine, California; the Solid State Products Division at Irvine, California; the Microelectronic Products Division at Newport Beach, California; and the Electron Dynamics Division at Torrance, California. Since June 1977, Division 79's Electro-Optical & Laser Production at El Segundo, California; Division 26's F-14 production at El Segundo, California; the Santa Barbara Research Center, at Santa Barbara, California and Spectrolab at Sylmar, California have initiated quality circles. The Ground Systems Group's Division 15 Manufacturing at Fullerton, California and the Tucson Manufacturing Division at Tucson, Arizona, have quality circles underway and other Hughes Groups and Divisions such as Space and Communications are investigating the program and have shown interest in becoming involved. At this time over eleven Hughes divisions with about 250 people are taking part in the Quality Circle program in the manufacturing areas. These Hughes Divisions are involved with all aspects of products and research of electronic and mechanical applications for commercial and military purposes.

Results

At the outset of the quality circle program there was some concern by management for the name of the program. Some felt with good reason that maybe the circle should be called a communication circle. Hughes experience, however, after two years has been that Quality Circle or QC Circle as a name is very acceptable. The word quality is helpful because employees and union people respect the importance of quality and they know that the circle program is not aimed at speeding up work. Although product quality is of primary concern to the circle, the circle's effort is also involved with any problem that affects the performance of the individuals or the group. Some results of the quality circle program are:

- Pre-amp spacers cracked and breaking during swaging operation requiring excessive rework - changed material.
- Excessive amount of defective material supplied to assembly line - supplier took corrective action.
- Adequate tools were needed for assembly - necessary tools were provided.
- Chemical cleaning procedures reviewed on volume priority basis - improves methods, yield, and quality.
- Front end assembly procedure simplified from three PI's to one PI - improves operator's understanding and performance.
- Sample boards redesigned for assembly - improved quality and assembly performance - large savings - $48,000/year.
- Ultrasonic cleaner used to clean parts - major reduction of defects and large savings - $31,000/year.

- Developed step-by-step manufacturing assembly procedures with photographs - improves training and performance.

- Inadequate space - improved through brainstorming.

- A classification system was developed to identify tools and equipment - saves time.

- Noise levels were reduced - improves assembly performance.

- Bonding manufacturing procedures not followed and inadequate - changes improve quality and performance.

- Packaging and planning problems were identified - changes improve assembly quality and performance.

- Quality control charts for major problem circuit boards displayed - improved operator performance and quality.

- Provided resistor color coding guidelines - improved assembly quality and yield.

- Parts list information made available for assembly personnel - improved performance.

In the quality circle program at Hughes we see a significant increase in the interest that circle people show in their jobs. This means that people involved in the program become more committed to doing their jobs properly. The circle program significantly improves communications between supervisors and employees, leading to improved operations and savings. Although some of the benefits of quality circles are not measurable, Hughes does use its C.I.P, (Cost Improvement Program) and P.I.P. (Performance Improvement Program) to help measure its results.

Time spent by employees in the quality circle program is compared to measurable costs and benefits from the program. Savings at this time are better than 4 to 1. Individual quality circles' vary significantly on cost benefits depending on the manufacturing area involved and the nature of the circle. One circle had a savings of 120 to 1 another 30 to 1. Some circle savings are difficult to measure. In all cases, however, the circles contribute to improved quality and performance.

Hughes Quality Circle Approach

The Hughes quality circle program is similar to Lockheeds' and the Japanese. Hughes agrees that training is very important to the effectiveness of quality circles and it focuses its training towards developing a team of people that work well together in identifying and solving problems. Hughes simplified training approach is directed at pareto analysis as a management tool for problem identification and priority setting and also it focuses on cause and effect diagraming as a tool to help team participation for problem solving. The Hughes training approach utilizes the existing skills and talents of the individuals in the circle in order to develop a team that can freely and effectively identify and solve problems.

The Hughes Quality Circle has from 5 to 10 people that volunteer for the circle and who do related type work in the manufacturing area. The manufacturing circle meets with their supervisor and a facilitator three weeks of the month for 1/2-hour to 1-hour leaving the last week free for monthly schedule deliveries. Many circles start with a 1-hour meeting and adjust down to 1/2-hour as the scope of problems are reduced. The supervisor is leader of the quality circle and in this manner line management responsibility is not changed. The facilitator has several jobs that are important to the performance of the quality circle. First, the facilitator should be trained in quality circles and therefore he provides an avenue for training the circle in its methods of defining and solving problems. Secondly, the facilitator acts as a middle person between the individual members such as the supervisor and employee. In this role the facilitator can be very helpful in increasing communications from very member of the circle. In this communication process the facilitator trains everyone to realize the importance of listening to everybody's ideas. Finally, the facilitator should spend about 1 hour for every 1/2 hour spent in meetings in helping the supervisor and members in solving the circles' agreed to problems during the week.

A question may be asked, "Why does the quality circle program work?" It works because the philosophy of the program is that people will take more interest and pride in their work if they can influence that work. The quality circle program is organized to encourage people to openly discuss and solve problems that affect them. This means that there is a safe free environment created with no fear of management retaliation. People enjoy the freedom of expressing their thoughts about their work. The quality circle program illustrates how individual employees know more about their own work than anyone else. The circle members also enjoy getting attention and help from engineering, supervision and others in reducing the conflicts they see in their work environment. The circle program also works because the members are recognized for their successful projects.

Summary

The quality circle program at Hughes Aircraft Company illustrates the following benefits that contribute to MISSION SUCCESS:

1. Improved communications between individuals and their supervisor and management.

2. Increased interest and commitment members have in their job and in their departments performance.

3. Problem identification by individuals that really know the problem.

4. Solutions to problems that are cost effective.

In other words quality circles increase the utilization of information and resources in order to enhance MISSION SUCCESS.

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Signetics' Personnel Effectiveness Program for Aerospace/Defense Components

Dr. Gerald R. Pieters

Key Words: Motivation, Integration - Differentiation, Organization Contingency Theory, Quality Improvement, Work Redesign, Business Teams

* From an 8% quality return rate of products by aerospace/defense customers in 1974 to a present day rate averaging 1-2% and improving further.

* From a situation where approximately 25 quality deficiency reports were written by government source inspectors in 1974 to a situation of an average of only one per year for the past three years.

* From a situation where corrective action requests were handled very slowly in 1974 with a backlog of over 100 requests unprocessed to a no backlog situation and immediate action today.

* From a situation of being an also ran competitor in 1974 to having the largest number of JAN qualified products of any competitor and as many, or more, NASA line certifications today as any competitor.

All of this has happened at Signetics since 1974. Why? What has been done? It would be nice to be able to point to one decision, one action that was responsible for these changes. However, such is not the case. A continuing series of decisions and actions were required and were built around organizational contingency and job design theory and our assessment of the implication of these theories for our success in the aerospace/defense market.

In this paper I am going to describe a number of the specific actions that have been taken by Signetics Corporation to structuring and organizing the company and the jobs of people in the company (across several levels) in a manner which would maximize our ability to service the unique and demanding requirements of the aerospace/defense industry. Since we believe that actions taken at all levels have contributed to employee motivation and effectiveness, I intend to describe these actions starting from the top management (corporate) level, then proceed to look at actions taken by the management of our Military Products division, and finally, to review some specific activities to improve performance, motivation, and satisfaction at the operator level.

Corporate Level Actions

Let me begin the discussion of specific Signetics' actions at the corporate level. Much of the guidance to our thinking about our organization and management practices comes from the organizational contingency theory of Lawrence and Lorsch. The theory suggests that companies operating in highly uncertain and complex business environments such as high technology electronics need to adopt organization and management practices that produce both a high degree of differentiation (i.e. much specialization of function and substantial differences among the orientations and thinking of employees in the specialized functions) and a complex set of mechanisms and roles to assure effective integration of the diverse functions. This theory has provided the basis for much of the company's effort at organization development (O.D.) and improvement since the formal beginning of the O.D. effort under the then new president in 1971.

In 1973, Signetics' management realized that the nature of the growth in the company's business, which had been dominated by growth in high volume, commercial product lines, had generated a need for both further differentiation and specialized integrating structures if we were to succeed and improve our performance in the aerospace/defense market place. The increasing product and processing complexity of I.C.'s and their relative importance to system performance was creating a need to provide more intense, dedicated focus on the lower volume, but more demanding requirements of the non-commercial business. Simply having a hi-reliability processing area as part of commercial manufacturing was not sufficient. Spec reviews, special qualifications, quality and reliability assurance, etc., needed to be the responsibility of a group of people whose specialized knowledge and primary focus was on products for the aerospace/defense market.

Therefore, after a series of discussions at the top management level, we made the decision to restructure a portion of the company and established our first market oriented (vs. product/technology oriented) division which is called the Military Products Division. A division manager was appointed and given P/L responsibility for the business as well as his own dedicated facility. Specialized functional resources were pulled together to be integrated within the division from the areas of marketing, finance, special (hi-rel) manufacturing and testing, engineering, and production control. A specialized military Q & R manager was appointed who reports to the corporate QRA manager but has a dotted line relationship to the division manager

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and functions as part of his staff. Within the sales department, separate groups were established to focus on, manage and improve the order processing and customer service functions, an industry sales manager's position has been developed to coordinate field selling activities, and, where feasable, geographically dispersed sales engineers have been given specialized key account assignments and made part of the Military Sales team. This team meets semi-annually with the division to identify, confront and resolve problems. Additionally, the assembly operations activity in the Orem, Utah plant has been virtually entirely devoted to processing parts to requirements of Military specification 38510.

As a result of these changes, the company achieved a focus on the business that had previously been impossible, even though many of the resources had already been spcifically oriented to the military business in the previous structure. What had previously been complex problems that might go unnoticed or unattended in the middle of other problems associated with very high volume, commercial business, were not only noticed and attended to but were the top priority problems of the people working in the military business division. Common problems across product lines were now being identified, confronted, and resolved in a coordinated manner by military division personnel who had the legitimate task of representing the company to our customers with our salesforce and integrating activities across all product lines.

The number of internal interfaces to be managed in the new structure was, if anything, increased. However, many of the needed interactions now took place within the division where common overall goals existed and where most of the people involved were located together within the same building. Substantial investments of time and energy were made in developing an effective management team and in clarifying roles and working relationships among the various functional groups. For nearly a two year period one of our internal organization development consultants worked with the division manager and his organization to help improve their effectiveness.

Dealing with people outside of the division was also helped greatly, especially in the areas of new products and service to customers, by the development of a separate Profit/Loss (P/L) statement for the division. The product division managers had always had worldwide P/L responsibility. Now, however, the impact and contribution of the Military/Aerospace business on his product line performance was not only visible, but another peer level manager shared his responsibility and was helping him to improve his overall performance. Changes in the company's accounting system were required to allow development of dual-counted P/L statements but the positive effect of this change in the measurement system (and associated reward systems) was immediate and obvious, especially as it impacted intergroup planning, decision-making, and problem solving.

Division Level Actions

As mentioned earlier, the decision was made to establish a separate division and specialized resources in key functions outside the division in order to achieve an appropriate level of differentiation and focus of resources and to build a permanent business structure to achieve the integration and teamwork necessary for success. The division management team, over time, found it necessary in some areas to provide even further levels of differentiation and specialization which in turn required additional roles and mechanisms for achieving needed integration. For example, as time progressed the organization began to "clean up its act" as a result of the increased ability to concentrate available energy on the tasks of managing the business. As improvements were made and some basic problems solved, more management energy could be focused on growing the business. One area of particular need concerned new products, both in terms of new designs/technology and in terms of bringing viable existing products into the division. To accomplish this, the division management team appointed four business teams to plan and coordinate activities to build the business in a specific product line. Membership on the team typically included representatives from marketing, specification engineering, product engineering, production control, manufacturing, quality and reliability assurance, and product/design engineering from the relevant product division. These groups are charged with identifying viable products and coordinating their energies to develop the needed capabilities, capacities, and logistics to bring those products to the military/aerospace marketplace.

One of the business teams is focused on an area of particular relevance to this conference on mission assurance. This group is called the Class B Business Team. Supplying products to S-level specifications is a complex business and requires a high degree of intergroup coordination and communication. Seeing to it that this coordination takes place is the business team's responsibility. In addition to use of the business team for achieving coordination, the division has also appointed program managers to assist in managing the complex logistics and status requirements

of their customers. They too are part of the business team.

Operator Level Actions

In looking at actions taken at the operator level, I'll begin by continuing some discussion as it relates to operators working on S-level products. Success in supplying S-level components requires highly trained, experienced operators certified as appropriately skilled for their work by the QRA organization. These operators are grouped under a production manager, who participates in the business team, whose sole focus is in S-level processing and products. This group was split off (another degree of differentiation) from a group that had already been set up to process newer and more complex products and had previously split from more standard processing lines to give it more focus.

One concern we have discussed as these sequential splits have been made and the work of the production lines made more specialized is that we avoid becoming so specialized that individual jobs become less meaningful and, therefore, motivating and satisfying. However, to date we have found that the effect of the changes is more in the direction of providing operators with more of a small work team environment focused on a portion of the business with which they can identify. This action is also consistant with other thrusts in the company aimed at assuring more meaningful and motivating jobs.

First, the company, with thrust provided by the President himself, is moving in the direction of assuring that all jobs in the company are designed such that every employee is involved in the management of their own work. Much work today, particularly at lower levels, consists primarily of carrying out tasks at the direction of a supervisor, i.e., "doing" tasks. The supervisor's role is to do the planning and controlling in an authority oriented relationship to the subordinate whose role is to respond as directed. Arrangements like these produce non-meaningful work, low motivation and untapped capabilities and energy.

Supervisory roles, on the other hand, viewed as involving goal oriented relationships and providing assistance to subordinates as they manage their work, lead to meaningful, motivating jobs that tap the energies and capabilities of all employees. M. Scott Myers, in his AMA book "Every Employee a Manager", covers this concept extensively. We feel we have a number of experiences in the company demonstrating the practicality of such an approach. Probably our most dramatic findings occurred a few years ago in one area when we recorded increases in line yield (a measure of quality and care in handling and processing) of 45% in a 4-week period after educating and informing operators of our needs and objectives and involving them in the planning and control of their work to achieve those objectives.

The concept of a supervisor's role as being goal oriented and assisting goal oriented operators in managing and carrying out their work has now been incorporated into the company's supervisory development program. Supervisors from the Military Products Division were among the first to be exposed to the program.

Another thrust is emerging from within the division towards providing more meaningful, motivating work at the operator level. Production managers became aware of an experiment with the use of a semi-autonomous (self-managing) work team on an assembly line for JAN product in our Orem, Utah plant (to be described in somewhat more detail below.) Some of the positive indications from the work in Orem lead them to explore several places where the self-managing team concept could help them. Their conclusion was that the complexity and generally non-standard nature of much of the Class S product processing and testing creates conditions where the flexibility and motivating potential of jobs in a self-managed work team could produce both improved performance (in terms of quality and improved through-put to assure more certain, timely delivery) and greater satisfaction. Work is now beginning on the evolution and development of the semi-autonomous team concept for Class S product. Consultative support to the effort is being provided by the Organization Development Manager of the Utah plant, who also consulted on the Orem experiment, to help avoid some of the problems encountered in Orem and to bring the benefits of the learning that has already occurred.

Orem Self-Managing Assembly Team

The decision to engage in a work redesign project in the Orem assembly operations was made after extensive study, data collection, and management education and discussion. Indicators that work redesign might be appropriate were high turnover and absenteeism, frequent production imbalance, limited cross-training of operators, and verbal inputs indicating alienation, morale and motivation problems. The Job Diagnostic Survey developed by J. Richard Hackman of Yale University was administered to production operators. Response patterns indicated job designs with low motivating potential but operators with generally high growth needs, high internal work motivation, high social

needs, and a high desire for skill variety, responsibility and challenge in their work. This pattern supported initial thinking in the direction of a group (vs. individual) oriented work redesign. A similar pattern but with low social needs would have suggested focus on individual work redesign.

A design team was formed consisting of an area supervisor, a line supervisor who had been selected to be the team advisor, a production operator, a quality control operator, an engineering technician, and the organization development consultant. Their recommendations were accepted and installed in a pilot operation in mid-1977. About four months later a second team was established on the night shift based on encouraging results from the first line.

Some of the changes instituted with the team line are as follows:

1) Team includes a team advisor (vs. line supervisor) whose role is advising, consulting, and liason to members.
2) Team determines line capacity each week based on product complexity, scheduled vacations, available expertise, etc.
3) Task assignments for individuals are decided within the team.
4) Many typical maintenance technician functions are performed by the team members.
5) All members are trained and certified as quality experts. Fewer external checks and use of QA as resource.
6) Cross-training of each other among members - pay goes up as more jobs are mastered.
7) All reports and information needed to do the job are available to team and they are taught how to read and use them.
8) Physical layout was redone to facilitate relevant interactions.
9) Performance is evaluated on contribution to team as well as individual performance.

Measuring the effects of these and other changes is difficult. In this situation the comparisons that have been made are with the performance of three other assembly lines running similar products. Over a six-month period we found absenteeism consistantly below the area average and labor efficiency averaging 8% above the area's performance. Unit costs were not apparently different, but overhead efficiency was improved substantially as a result of reductions in needed overhead support to the team, such as supervisors, technicians, and production aides for training and helping to achieve line balances.

Of particular interest to this mission assurance conference is the issue of the impact of the work redesign on quality performance. It is in this area that changes of the type described have typically had more impact (as opposed to the area of productivity). In the first few months, the data we had indicated that the team line quality was below that of the area and then moved quickly to a higher level than the more traditionally structured lines. Further looking into the data, however, pointed out that what had happened was that the operators on the team line, given full quality responsibility, had responded by being overly critical and rejecting some product that the QA organization would have accepted. This did not change until assurance and support was provided by the QA organization.

Further, the initial team line was set up on the day shift and was highly visible. The operators responded and became overly careful in their inspections. The second line. set up on the graveyard shift, where there was less visibility and external pressure, further demonstrated the positive impact of this change on quality performance. Quality acceptance rates began at very high levels and remained there. The levels were so high in this case that additional external checks were deemed necessary and were instituted to verify the accuracy of the operator's inspections. The conclusion was reached that the inspections were accurate and that, in fact, higher qulaity results were achieved than we had previously experienced.

Summary

This paper has described a variety of changes that have been made at Signetics, from the corporate level to the operator level, to address to the needs of the military/aerospace market and the needs of our employees more effectively. In virtually every case the result of the changes have created more motivationally rich jobs and better focus on the tasks involved leading to improved performance and, therefore, higher levels of satisfaction. From the perspective of a parts supplier, we believe that the effects of these changes have assisted, and will continue to assist us and our customers with the task of mission assurance.

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CARE

W. E. Magnuson

The following is a brief outline of the Convair supplier awareness program:

The program is introduced by the Manager of Procurement or the cognizant Purchasing Agent who explains the business outlook for Atlas/Centaur and the importance of our suppliers' contribution with particular emphasis directed towards the group we are talking to. A member of the team then describes in detail the use of the equipment produced by that particular audience. A color, sound movie "Countdown to Success" is then shown. This film shows some of the accomplishments of the system and projects what will happen in the future.

An illustrated lecture called "CARE" follows in which the listener is reminded that it always costs more to do the quality job the wrong way, that it costs material, time, customer dissatisfaction; that the causes for doing the quality job the wrong way are unfamiliarity, failure to follow procedures, doing things from memory, etc. The need for an error-free environment is stressed. The necessity to develop personal concern, awareness, pride, and the need for improvement - that personal concern must become a habit - is emhasized; that in order to achive this goal we must have an understanding of quality related objectives and the new enviroment that surrounds all of the employees in American industry.

The employee's part in the products produced is emphasized. The absolute importance of our customer and the fact that since each of us uses something from someone else, we all are in fact customers is discussed. It is then pointed out that everyone in the company is responsible for quality, cost, schedule and new business. The thesis that the whole concept of CARE requires personal commitment through personal awareness, concern and enthusiasm is developed.

The program takes about 45 minutes. We have given it approximately 150 times to approximately 10,000 people. Conservatively, reception has been very good - in fact - the usual comment is, "Will you come back and give the same message to all of our employees".

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Mr. W. E. Magnuson is a 40 year veteran of the aerospace industry. Beginning his career at the Douglas Aircraft Company while still in school. For the last 35 + years first with Vultee Aircraft, then Consolidated Vultee or Convair. He has held a variety of management positions in experimental aircraft work as well as operation management. Currently is a member of the Quality Assurance organization at Convair in San Diego. Over the years he has been active in business affairs including National President of the National Management Association. A teacher of Management Discipline in the San Diego Community College System. He was born in Minnesota, educated in Illinois and California. He and his wife Barbara have two children, Pamela and Dennis.

Motivational Programs at Boeing Aerospace

Gene Peretti

KEY WORDS: Communication, Motivation Techniques, Productivity, Crosstalk, Problem Analysis, Line Management, Satisfiers, Feedback, Job Related Techniques

The general feeling about Zero Defects some ten years ago was, it was one of the things we all did before we really knew anything about the science of motivating employees.

Since Zero Defects we have experienced Satisfiers and Dis Satisfiers. We've identified X and Y managers, we've conducted surveys, we've graded and classified groups of people - all in an effort to teach us something about people at work. The only difficulty with most of this new knowledge is that such techniques are very difficult to communicate to Line Management and almost impossible to communicate to the troops - so the experts end up talking to themselves. As bad as Zero Defects was in the eyes of most behavioral scientists, it was one program that everyone knew about and that most people understood. I'm not suggesting a return to Zero Defects, but there's a lesson here, if we can't come up with an objective that is clearly understood by every manager involved and that can be just as clearly communicated to everyone on the program, we're only fooling ourselves. No improvement will be made, objectives and targets will be ignored, missile hardware will fail and line rejections will continue to pile up unless the specific goal and objectives are clearly communicated to every employee.

Chart 1

- o The Boeing Industrial Relations role in productivity has to do with the effective utilization of the work force.
- o Obviously, capital investment has traditionally been the big swinger in improved productivity. I would estimate that the people impact on productivity in BAC (Boeing Aerospace Company) is something like 20% to 30% as compared with 70% to 80% for capital investment in new machines.
- o We should not underestimate, however, the importance of people as a resource. If we do our job right, the result can have a substantial impact on company profit.

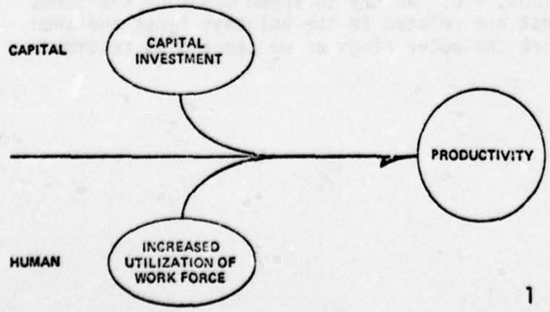

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Chart 2

As shown here, we get a lot of help from our Corporate Headquarters in terms of employee related benefits. The effect that such benefits have on the "bottom line" is sometimes difficult to measure, but without this base we would be hard pressed to build workable improvement programs to increase productivity. You've got to provide the basics first, before you can motivate people.

Corporate

- Company service awards
- Boeing news (weekly)
- Recreation programs
  - Club memberships
  - Tennis club
  - Picnic kits
  - Fishing Derby
  - Discount tickets
  - Travel packages
- Compensation programs
- Share-the-Ride program
- Retirement Planning Program
- Boeing Employees Good Neighbor Fund
- Boeing Employees Disaster Relief Fund
- Employee Christmas Party
- Employee benefit plans
  - Insurance packages
  - Voluntary Investment Plan
  - Financial Security Plan
  - Vacation
  - Sick leave
  - Retirement Plan
- Management Information Bulletin (daily)
- Mariner baseball
- Facilities modernization
- Employee awards policies
- Community contributions (facilities, money, time)
- Employee Self-Development Program

Chart 3

In setting the stage for a discussion of BAC Productivity programs, I feel it's vital to relate such programs to the unique characteristics that exist in BAC. We're a "job shop" with a highly diversified product mix, that usually results in contract runs of less than twenty items.

With short runs, it's difficult to make an experience curve pay off, you have to move people from program to program and you're dealing with a constant retraining process. All of this can cost a lot of money and our job is to minimize such costs and to develop the kind of people that can be productive in this kind of business environment.

Our approach to productivity through people is designed to meet the unique needs of each organization and it's product line and employee mix.

Boeing Aerospace Company Approach

- Recognize unique BAC features:
  - 45 to 55 named programs (ongoing)
  - 80% of deliveries have quantity of less than 20 items
  - Items from heavy steel to microelectronics
  - Many types of customers
  - Leads to a diversified organization (nontraditional)
- Develop diverse motivation programs to accommodate:
  - Organizational structure and skill mix
  - Management style of leader
  - Prime program objectives
  - Feedback to employees
- Focus on BAC as a good place to work:
  - Personalized approach
  - Challenge of new programs

Chart 4

Before I get into specific techniques, I'd like to point to some of the "people" problems that deter productivity and impact quality that can influence improvement in these areas if we know what the facts are and if we can get management to cooperate with us in applying a fix. It would be interesting to know how you would rate these nine items in order of importance. A recent study of BAC Operations management placed negative management attitudes as number one and low employee morale as number two. I'm going to talk about these items at the end of the pitch under impediments.

Deterrents to Productivity

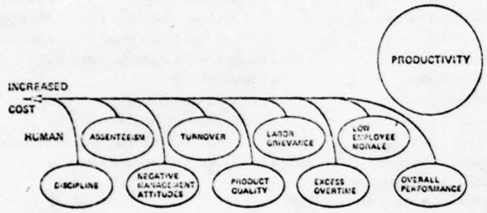

Chart 5

Let's look at "people" techniques. This is not a complete list, but it is fairly representative of the wide range of specialized techniques that have been in use in BAC for some time.

Our approach has been to work with each principle BAC manager to determine his approach, needs and management style, and then to tailor a program for him using these techniques as tools.

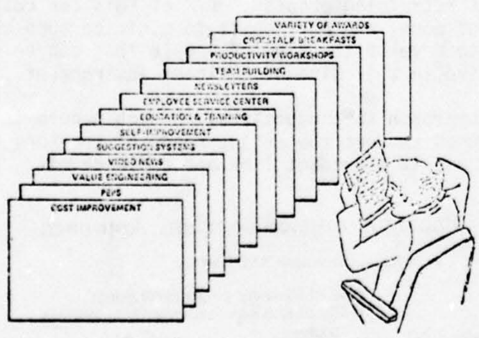

Chart 6

In applying the techniques (shown on the previous chart), we point out to Line managers the difference between techniques that impact profit (schedule, cost and quality) and others that affect work environment or the family and community.

Chart 6 (cont.)

As shown here, these are job-related techniques.

What Is the Objective ?

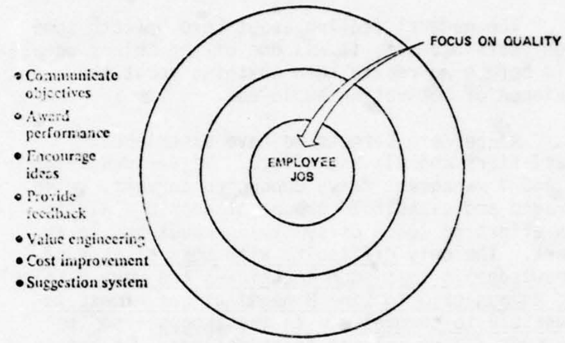

Chart 7

This is an example of work environment techniques. Such improvements are necessary and should be made. However, in terms of productivity and quality they are sometimes difficult to measure.

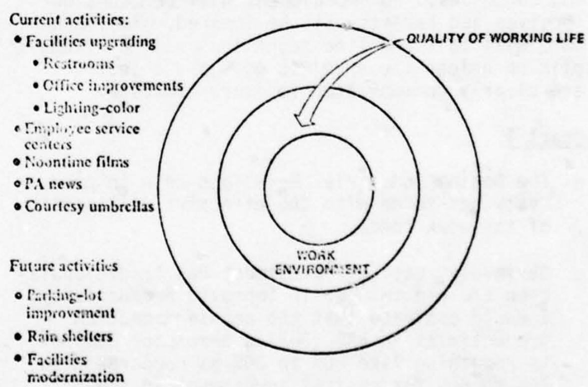

Chart 8

Even further removed from profit, but nevertheless helpful, are such items as golf tournaments, tennis clubs, etc. We try to spend money on the items that are related to the bullseye first and then work the outer rings as we can and as required.

Chart 8 (cont.)

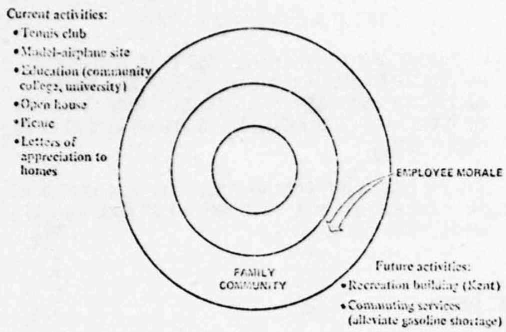

Chart 9

This illustrates the sequence of events of a typical people program in one of our BAC organizations.

As shown, we attempt to relate everything we do to the organization's business objectives. That process helps to assure that profit and productivity will be impacted and also that we get the top manager's support. He is obviously going to be behind a program that directly impacts his bottom line and his incentive.

Motivation Program Planning Cycle

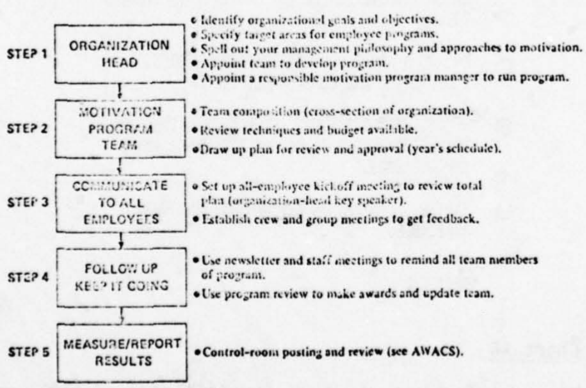

Chart 10

This chart shows the individual programs and the fact that all of the major organizations have participated with us in the development of a <u>tailored</u> program.

Each of these organizations has a specialist appointed part time or full time to make sure the program gets communicated and that it produces results.

Chart 10 (cont.)

New and Revised Motivation Programs for 1977

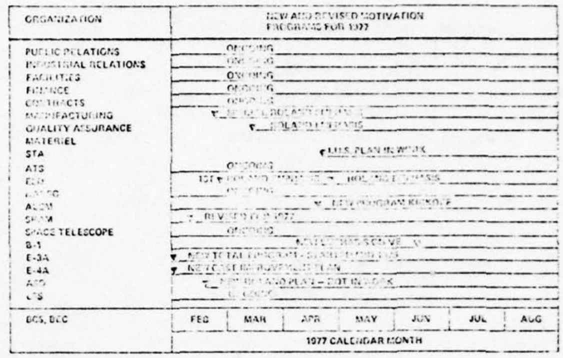

Chart 11

By way of illustration, here's the kind of Wish List that usually comes out of the early meetings with management.

Roland Motivation "Wish List"

- Inside parking for all salaried employees.
  - Space is available to accommodate people.
  - IR and Security approval required.
- Dedicate 1 equivalent BAC trip award ($4,000 value) to Roland program
  - Use to fund approximately 10 trips for two to Disneyland
- Monthly luncheon with program manager for team demonstrating greatest accomplishment on recovery targets (with Selby and Keister, as necessary).
- Roving clock/plaque award presented to monthly team achievers.

Chart 12

The Employee Service centers that have been set up at Plant II, Kent and Development Center are another example of the kind of technique that can have a positive impact on employee self-development and employee participation in company sponsored programs.

Chart 12 (cont.)

EMPLOYEE SERVICES CENTER

- FULL RANGE OF SERVICES FROM NEW HIRE THROUGH RETIREMENT

TRANSFERS	RECREATION
EEO	EMPLOYEE BENEFITS
COUNSELING	VOTER REGISTRATION
LEAVES OF ABSENCE	NOTARY SERVICE
SOCIAL SECURITY	LIFELINE
SHARE-THE-RIDE	INCOME TAX FORMS

- TRAINING MATERIAL AND FACILITIES — LEARNING CENTER
  - ON-HOUR COURSES
  - OFF-HOUR COURSES
  - SELF-TAUGHT
  - INSTRUCTED
  - VIDEO, AUDIO AND VISUAL EQUIPMENT
  - ROOMS AND EQUIPMENT AVAILABLE FOR SHOP CREW MEETINGS

- LOCATED IN THE MOST CONVENIENT FACILITY FOR THE MAJOR USERS

KENT-OFFICE AREA	DEVELOPMENTAL CENTER - FACTORY
PLANT II - FACTORY	

Chart 13

A new effort that grew out of the Roland cost problem is our Industrial Relations sponsored Crosstalk Breakfasts.

The way we're organized in BAC, there is a critical need for close and effective communication between each program manager and all levels of the support organizations.

Objective

Crosstalk brings the lower level managers into a meeting with Program managers that would not otherwise take place. It's also a recognition experience for lower level managers so selected.

Chart 14

These sessions also involve Finance, Industrial Relations, Materiel, Quality Assurance and other such support people.

Chart 14 (cont.)

WHAT IS A CROSSTALK BREAKFAST?

- THE PURPOSE OF A CROSSTALK BREAKFAST IS TO BRING PERSONS INVOLVED WITH A SPECIFIC PROGRAM TOGETHER IN A RELAXED AND INFORMAL ATMOSPHERE, TO REVIEW KEY PROGRAM OBJECTIVES AND POTENTIAL PROBLEM AREAS, AND TO DISCUSS WAYS TO AVOID THOSE PROBLEMS.

- INVOLVED PERSONS ARE THOSE WHO CREATE THE WORK TO BE DONE (PROGRAM PERSONNEL), AND THOSE WHO DO THAT WORK (SUPPORT ORGANIZATION PERSONNEL).

Chart 15

The objectives here are program related and often involve discussions of cost, schedule and quality--the importance of holding cost in line with program commitments, the impact of overruns on continued business and future sales, the long term impact of current performance on future business.

OBJECTIVES

- ESTABLISH CLOSER COORDINATION AND IMPROVE WORKING RELATIONSHIPS BETWEEN SUPPORT ORGANIZATIONS AND ONGOING PROGRAMS IN A LESS FORMAL SETTING.

- ALLOW PROGRAM AND SUPPORT SUPERVISORS THE OPPORTUNITY TO MEET AND TALK TO EACH OTHER, AND TO A PROGRAM MANAGER ON PROGRAM PROBLEMS WHICH INVOLVE SCHEDULES, QUALITY, DELIVERIES, ETC.

- CREATE A GREATER DEGREE OF TEAM SPIRIT, COOPERATION AND UNDERSTANDING.

- *RECOGNIZE THOSE FIRST LEVEL SUPERVISORS WHO DEMONSTRATE COST REDUCTION AND OPERATIONAL IMPROVEMENTS.

- INVITE CUSTOMERS AS APPROPRIATE AND WHEN AVAILABLE.

*OPTIONAL

Chart 16

The organizations shown on the left side of this chart are Harry Goldie's support team and the programs on the right are the prime business opportunities for BAC.

Without clear lines of communication between programs and support organizations, the unique and sometimes tough performance commitments of these programs may not be achieved.

Chart 16 (cont.)

WHO IS INVOLVED?

SUPPORT PERSONNEL	PROGRAM PERSONNEL
CONTRACTS	ALCM
ENGINEERING SUPPORT	E-3A
FACILITIES	ROLAND
FINANCE	B-1 AVIONICS
INDUSTRIAL RELATIONS	E-4A
MANUFACTURING	PLSS
MATERIEL	MINUTEMAN
PLANNING	C-14
QUALITY ASSURANCE	
ELECTRONICS SUPPORT	

Chart 17

We've held three breakfasts over the last six months and plan three more before year end.

The last breadfast was video taped and features the Roland program with Jerry King -- We're going to run that television show for all shop and office areas involved with Roland.

I've supplied cups and pins to you. These are inexpensive items that the first line guys can take back to work and demonstrate that they were selected to participate.

SUMMARY

- NEED TO FIND BETTER WAYS TO COMMUNICATE BETWEEN SUPPORT ORGANIZATIONS AND ONGOING PROGRAMS.
- NEED TO STIMULATE INTEREST AND SUPPORT AT SUPERVISORY LEVEL.
- NEED TO PROVIDE CROSS-FUNCTIONAL RECOGNITION OF INDIVIDUALS WHO PROVIDE SUPPORT TO EACH OTHER.
- NEED TO EXPOSE SHOP AND OFFICE SUPERVISORS TO PROGRAM MANAGER'S OBJECTIVES.
- NEED TO BUILD TEAM SPIRIT THROUGH BETTER COMMUNICATIONS.

Chart 18

A new program that we plan to kick off this fall is called "PAC" for "Problem Analysis Cooperative". It's an off-shoot of PEPS, the Participative Employee Problem Solving program that was in operation for about three or four years.

PAC

PROBLEM
ANALYSIS
COOPERATIVE

Chart 19

As shown on this chart, PAC is an improvement on PEPS. The basic change is the involvement of the Line Supervisor as a facilitator instead of the Industrial Relations specialist.

The problem with PEPS was when the Industrial Relations facilitator left the group, the group would soon fold up for lack of leadership. Also, the Line supervisors objected to their people going to PEPS meetings without them.

ADVANTAGES OF PAC

- LESS COMPLICATED THAN PEPS
- MORE DIRECT - NO I.R. INTERVENTION
- I.R. INVOLVED ONLY IN TRAINING
- LINE SUPERVISOR DIRECTLY INVOLVED AS FACILITATOR AND MEMBER OF COOPERATIVE
- IMPROVED COORDINATION AND FEEDBACK
- SUCCESSFUL OPERATION DIRECTLY ATTRIBUTABLE TO ORGANIZATION
- ACHIEVEMENTS TIED DIRECTLY INTO ORGANIZATION GOALS

Chart 20

PAC then is a job-related problem solving technique that is aimed at improving productivity by "working smarter"

PAC IS --------

A SYSTEM WHICH RECOGNIZES AND UTILIZES THE ABILITY OF EMPLOYEES TO IDENTIFY AND SOLVE PROBLEMS DIRECTLY RELATED TO THEIR WORK SITUATIONS.

Chart 21

Problems are surfaced by employees and solutions for resolution are offered by the group using a problem solving technique.

METHOD OF OPERATION

A GROUP OF 6-8 VOLUNTEER EMPLOYEES WILL MEET WITH THEIR SUPERVISOR TO ANALYZE A WORK-RELATED PROBLEM AND ARRIVE AT A SOLUTION TO THAT PROBLEM

Chart 22

The group size is limited to 6 - 8 volunteer employees who meet with their supervisor. The fact that employees volunteer, helps to assure that interested people will be involved on teams.

Chart 22 (cont.)

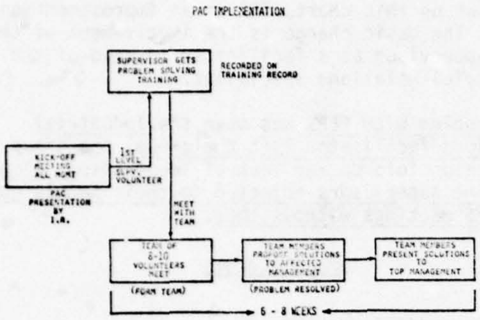

Chart 23

This flow chart illustrates the primary steps that take place in setting up a typical problem solving team.

In PAC we plan to formalize our Supervisor training in problem solving to include a comprehensive course on brainstorming, group dynamics and how to work with a group rather than give directions. Such training will be recorded in the supervisor's training record and his success with his group will be a plus factor in his rating.

See above chart for reference.

Chart 24

The output of PAC groups is primarily to solve problems but as shown here, there are a number of side benefits worth noting. It's also worth noting that the Suggestion System doesn't surface all of the job related problems. Many problems are too complex for suggestions, or employees have difficulty getting their ideas down on paper.

PAC BENEFITS

- IDENTIFIABLE DOLLAR SAVINGS
- EMPLOYEE SATISFACTION
- INCREASED PRODUCTIVITY
- BETTER UNDERSTANDING OF COMPANY GOALS
- INCREASED EMPATHY
- IMPROVED COMMUNICATION SKILLS
- BETTER PEER RELATIONSHIPS
- HEIGHTENED AWARENESS OF COST IMPACT

Chart 25

To sum up -- the supervisor leads the group and gets recognition for his training and success with problem solving.

One final point -- the management from the top down must be committed to the program and demonstrate that commitment by encouraging lower level managers to work with groups and seek better ways to do the job.

Chart 25 (cont.)

CRITERIA FOR SUCCESS

- SUPERVISOR IS A MEMBER OF CO-OP
- MANAGEMENT COMMITMENT IS MANDATORY
- ACHIEVEMENTS MUST BE RECOGNIZED
- COMPANY-WIDE PUBLICITY
- EMPLOYEES IDENTIFY PROBLEMS AND ARRIVE AT SOLUTIONS
- PROBLEMS MUST BE CURRENT AND WORK-RELATED
- CO-OP MEMBERSHIP MUST BE ROTATED

Biography

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Mr. Peretti began his career at Boeing in 1951 as an Industrial Engineer, was appointed to his first management position in 1956. He has held management positions in Manufacturing, Engineering, Quality Control, Contracts, Business Management and Industrial Relations. He is currently the Boeing Aerospace Company Improvement Programs Executive with program responsibility for the Suggestion System, Value Analysis, Value Engineering, Cost Reduction and Performance Improvement programs.

He is currently National Chairman of the Board of the American Society for Performance Improvement, a permanent member of the NASA Aerospace Awareness Council and member of the Society of American Value Engineers. In July 1976, he was appointed Chairman of the Cost and Value Management Division of the American Defense Preparedness Association for the 1976-1978 term.

Over the past six years, Mr. Peretti has lectured to university, society and association audiences on subjects relating to people involvement and improved performance techniques. In May 1976, he obtained certification by the American Society for Performance Improvement as a "Professional Manager of Human Resources".

Management Motivation and Contractual Incentives

David R. Stevenson

Key Words: Training, Motivation, Incentive

Abstract

This paper is an abbreviated description of the Honeywell Avionics Division, St. Petersburg, Florida location, training and motivation programs.

Introduction

Honeywell St. Petersburg has comprehensive training and motivation programs directed to assuring that personnel are qualified and understand the need for high quality, cost effective performance to assure contractual requirements are met. The programs assure that engineering, operating and supervisory personnel are trained, qualified, and where required, certified to customer requirements.

Training

Operating Personnel

Newly-hired operating personnel are required to take 40 hours of classroom instruction in soldering and be certified prior to performing a production or inspection function. They must produce samples demonstrating soldering capability prior to being certified. Certification is granted by the Central Training School. Upon assignment to the function, these personnel are given vestibule and on-the-job training in the particular soldering techniques they will use to produce contractually acceptable product.

In addition to soldering, personnel who will be performing plastics operations- e.g., product encapsulation, conformal coating - are given a 40 hour classroom course in mixing and applying plastics. As with soldering, they must make samples to demonstrate their skills prior to being certified by the Central Training School. They are also given vestibule and on-the-job training prior to working on the product.

Personnel who will perform resistance welding are certified in a similar manner as those certified for soldering and plastics.

Special processes - e.g., welding, heat treat, plating, plated wire processes- are taught in vestibule and on-the-job training programs. Personnel performing these processes are certified only after acceptable demonstration samples are completed.

Certifications are rescinded if a person is not performing the function for which certified, workmanship falls below accepted standards, or specified time intervals for recertification have lapsed. Records are maintained on each person and are under continuing assessment to assure that their certifications are not expired and their performance remains up to goals.

Systems Personnel

College level classes are available at several universities and colleges in the immediate St. Petersburg area for engineers to update their technological backgrounds. In addition, in-house courses in current technologies are taught by university instructors and professors, and qualified Honeywell personnel.

Test technicians are required to have completed and graduated from an accredited technical school prior to being hired. College and technical institute courses are available to these personnel to update their knowledge to new technologies. In-house courses are also taught to cover special technologies and unique program characteristics.

Product Logistics Support Personnel

Logistics Support personnel operate in the field. They are engineering level personnel, supported with site managers on major programs. In addition to their college educations, they are given in-house and site training in the unique requirements of the programs to which they are assigned. Courses for this training are documented in a Training Services Course Catalog. Correspondence training is also available to personnel while in their field locations.

Incentive for Self-Improvement

All personnel are entitled to tuition aid for job-related training at approved colleges, universities or technical institutes. Reimbursement under the program is based on achievement - i.e., grades or marks received - for each course completed.

Motivation

Motivation programs in place include a division-wide STEP (Strive Toward Error-free Performance) program, periodic communications sessions at all levels in the organization, recognition awards for length of service, and program manager meetings with program personnel to apprise them of goals and accomplishments, problems, and future projections.

Incentive Programs

The STEP program recognizes individual contributions to design, process, operational and cost improvements. Recognition is given in award meetings and via company newspapers. Awards can go

up to several hundred dollars in savings bonds.

A Quality Awareness Program has been instituted to recognize operating personnel and supporting groups for achieving product yield and defects per unit goals. Awards include luncheons for short range accomplishments, and monetary recognition for long range accomplishments.

Service Award Luncheons and publicity in Honeywell newsletters are a continuing feature of our motivation efforts. Recognition is given not only for length of service, but also for outstanding accomplishments.

Communications

Communications meetings are held by top management for all supervisory personnel twice yearly. Quarterly department director meetings are held with all levels of personnel in the respective department. Supplementing these are weekly meetings between directors and their staffs, and monthly meetings by line supervisors with their hourly and salary personnel. All communications meetings are directed toward achieving face-to-face dialogue on problems, questions, and projections. These meetings have been highly successful in creating a unified drive toward the objectives of customers and Honeywell management.

Program Managers hold meetings as appropriate to enlist emphasis on solving problems, to give recognition for achievement, discuss business projections and other information related to program goals. Astronaut visits, customer visits, launch visits, and customer furnished films are a part of this motivational effort.

Measurement of Effectiveness

Overall effectivity is reported in a computerized Quality Measurement System (QMS-200) and computerized schedule/cost reports. QMS-200 provides yield and defects per unit by program, work centers, operator and process. The system can be interrogated for any element contained in the history file - e.g., part number, assembly number, problem definition (cause/defect code), etc. Schedule/cost reports show schedule and cost positions by project, charge number and supervisor. It provides for daily input and output, produces periodic summaries and is a subject of periodic top management review.

Summary

Honeywell St. Petersburg's training and motivation programs begin with new hires and are continuing elements in employees' job assignments. They provide incentive, awards, review and corrective measures. The programs are baselined to division-wide policies and provide contract incentive awareness for each program in-house, as well as anticipated new programs.

Biography

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David R. Stevenson was born in Kansas City, Missouri. He attended Kansas University, Metropolitan College in Kansas City and St. Petersburg Florida Junior College. He became associated with the Kansas City Division of Bendix Corporation in 1950 and was instrumental in initial development of product test facilities and establishment of a total quality assurance operation. He is currently Manager of Process Quality Assurance at Honeywell, St. Petersburg, Florida, responsible for Quality Engineering, final product acceptance, process development and support, Acceptance Testing and Inspection operations. He has participated in a number of quality seminars throughout the country.

Training/Motivation Goals

- Workshop
  - Define SAMSO counter production practices and philosophies
  - Provide effective mission assurance related recommendations
  - Define recommended standards of operation to SAMSO
  - Define need for on-going workshop sessions
- Honeywell
  - Provide a training/motivation program that is cost-effective, performance oriented, and supportive of mission effectiveness
- Systems Personnel
  - College level education
    - Technology updates
      - In/out-of-house training
  - Program familiarization
    - Program orientations
    - System mission/effectiveness
  - Testing and test equipment
    - Accredited technical schools
    - Test managers - engineers

1/18/77

PRODUCT ASSURANCE TRAINING & ORIENTATION PROGRAM

SUBJECT	LEAD DEPT. (P.A.)	DURATION
P.A. SPECIFICATIONS	P.A. PROGRAMS	
1. INTRO TO SPEC TREE	P.A. PROGRAMS	1.5 HRS.
2. DoD QUALITY SPECS. 45208 & 9858	P.A. PROGRAMS	1.5 HRS.
3. CALIBRATION/METROLOGY 45662	PROCESS Q.A.	1.0 HR.
4. NON-CONF. MAT'L. & CORR. ACT. 1520	CENTRAL SERVICES	1.0 HR.
5. PROCUREMENT QUALITY 1535	CENTRAL SERVICES	1.0 HR.
6. FBM P.A. REQUIREMENTS 21549	P.A. PROGRAMS	1.0 HR.
7. NASA P.A. SPECS (5300 SERIES)	P.A. PROGRAMS	2.0 HRS.
P.A. PROGRAM PLANNING & MANAGEMENT		
8. INTRO TO PROGRAM PLANNING	P.A. PROGRAMS	1.0 HR.
9. IMPLEMENTATION OF PROGRAMS	P.A. PROGRAMS	1.0 HR.
10. PROGRAM REPORTING & ASSESSMENT	CENTRAL SERVICES	1.0 HR.
P.A. POLICIES & PROCEDURES - U-ED 23036		
11. ADMINISTRATIVE POLICIES & PROCEDURES (A ,B, C)	P.A. PROGRAMS	1.5 HRS.
12. SECTION D - QUALITY SYSTEM - D1-D3	P.A. PROGRAMS	1.0 HR.
13. D4.1 - D4.5	PROCESS Q.A.	1.5 HRS.
14. D4.6 - D4.13	PROCESS Q.A.	1.0 HR.
P.A. POLICIES & PROCEDURES - U-ED 23036 (CONT'D)		
15. D5-D10, D15, D15.1, D16	CENTRAL SERVICES	2.0 HRS.
16. D11	PROCESS Q.A.	2.0 HRS.
17. D12	CENTRAL SERVICES	2.0 HRS.
18. D17 - D20	CENTRAL SERVICES	1.5 HRS.
19. D21, D26	MATERIEL Q.A.	1.5 HRS.
19A D25	COMPONENTS P.A.	1.0 HR.
COST OF QUALITY		
20. COST OF QUALITY CONCEPTS	CENTRAL SERVICES	1.0 HR.
21. COST OF QUALITY HONEYWELL APPROACH	CENTRAL SERVICES	1.0 HR.
22. WORKMANSHIP STANDARDS	CENTRAL SERVICES	1.0 HR.
23. SOFTWARE	MATERIEL Q.A.	1.0 HR.
TOTAL QUALITY CONTROL	PROCESS Q.A.	
24. BUSINESS QUAL. MANAGEMENT	PROCESS Q.A.	1.0 HR.
25. QUALITY CONTROL MANAGEMENT	PROCESS Q.A.	1.0 HR.
26. ENGR. TECHNOLOGY OF QUAL. CONTROL	P.A. PROGRAMS	2.0 HR.
27. STATISTICAL TECHNOLOGY OF QUAL. CONTROL	SPECIAL PRODUCTS	3.0 HRS.
28. APPLYING TOTAL QUALITY CONTROL AT H.I.	PROCESS Q.A.	1.0 HR.
29. QUALITY EDUCATION & TRAINING	PROCESS Q.A.	1.0 HR.

- Operating Personnel
  - Basic training programs
    - Central training school for soldering, welding, plastics
    - Certification of personnel
      - Production operators/ quality inspectors
    - Recertification requirements
      - Time lapse, performance, job assignment
  - Program unique training
    - Vestibule and OJT
    - Special processes/unique criteria
  - Certification/recertification
    - Monitored via computer program
- Product Logistics Support Personnel
  - College level education
  - Product technology, logistics, program courses
    - Training services course catalog
    - Correspondence courses for field personnel
    - Available to other personnel
  - Program familiarization
    - Major program site managers
    - Program orientations
- All Personnel
  - Tuition aid
  - In-house courses
  - Vestibule and OJT
- Special/New Processes
  - Examples - plated wire memory, tunnel build, heat treat, plating, non-destructive inspection, etc.
  - Specific training courses in place
  - Certification/periodic recertification required
    - Time lapse, performance, job assignment

- Records
  - Individual accounting of cert. status
  - Maintained/verified by product assurance and supervision
  - Effectiveness measurement
- Effectiveness Measurements
  - Computerized quality measurement system (QMS-200)
    - Yield and defects per unit
      - Work centers
      - Project
      - Major problem highlights
    - Daily exception reports
    - Operator performance report
    - Process reports
    - Summaries
      - Management level
      - By project
      - Defect summary
    - Interrogation capability
      - By part number
      - By assembly number
      - By problem definition (cause code)
      - By operator
      - By program
      - By process
  - Computerized cost reporting
    - Daily input/output
    - By project charge number
    - By functional area (supervisor)
    - Periodic summaries
    - Periodic management reviews
- Motivation
  - Division-wide program
    - Strive toward error-free performance (step)
    - Individual recognition and monetary awards
    - Management support and participation
  - Quality awareness program
    - Group incentive program
    - Group recognition and monetary awards
    - Area/program oriented
    - Joint quality production
    - Division implementation
  - Program recognition
    - Periodic briefing of personnel
    - Success recognition
    - Customer provided films and lectures
    - Astronaut visits
    - Launch visits/tours
  - Periodic roundtable discussions
    - Director level quarterly (to all personnel)
    - Management staffs weekly
    - Operating personnel monthly
- Summary
  - All personnel trained/certified/recertified
  - Division-wide motivation programs
  - Communications roundtables
  - Detailed records maintained and utilized
  - Continuous effectivity measurement
    - QMS 200
    - Cost reports
    - Training/cert records

Concerns

- Diversity in government-imposed requirements
    - Variances between government agencies
        - Examples
            - Space shuttle - 30 day recert
            - Navy programs - 6 months recert
            - Special requirements for standard processes
    - Variances within government agencies
        - SAMSO - parochial critiques based on individual PCO perceptions/interpretations
    - Impact contractor costs
    - Questionable contribution to mission effectiveness

The Product Assurance Training Program at The Aerospace Corporation

Allan J. Boardman

Key Words: Training, Product Assurance

In mid-1976, as part of an overall introspective examination of potential improvements we at the Aerospace Corporation might make in fulfilling our role in mission assurance, a simple but relatively novel educational concept was born. The idea was to present an in-house on-going series of lectures, workshops, demonstrations, laboratory sessions, etc, open to Aerospace and SAMSO alike and aimed at a broad-based upgrade of skills and sensitivities in the product assurance disciplines. In this paper I will briefly describe the nature of the concept which has developed into the present product assurance training program, and comment on its effectiveness.

As I am sure most of you are well aware, the Aerospace Corporation serves SAMSO as the principal source of General Systems Engineering and Integration (GSE&I) for a large number of Air Force space and missile programs. Our company has a technical staff of some 1700 engineers and scientists specializing in the various disciplines necessary to perform this GSE&I role. A large fraction of the staff performs a program office function working closely with our customer in the technical management of each project. Another large group is organized by technical discipline with the engineers providing specialty services to each of the programs as needed. These two groups operate as a conventional matrix organization.

When, two years ago, we set about looking for methods of self-improvement several thoughts arose. Wouldn't it be nice if, for instance, it were somehow possible to take some deliberate steps to share certain "smarts" among engineers with the objective of making more of our people aware of some key issues which affect mission success probability? Can a control systems expert be trained to recognize the inappropriate use of hydraulic fittings, or an optical analyst sensitized to notice shortcomings in some parts handling procedure? Also, wouldn't it be nice if it were possible to get more mileage out of certain specialists--take them out of the one-on-one firefighting mode and put them in a position, at least part-time, where they could train or educate many people at once? These and related ideas germinated and became the embryo of the product assurance training program. The concept took shape in the summer of 1976 and in September of that year we announced the start of the PATP.

Initially, two types of sessions were offered: short sessions, one or two hours in length, were held on a variety of relevant topics. These were open to all members of the Aerospace/SAMSO community with no registration or management approval required. Some topics could not be well presented on such a scale and were therefore offered as extended sessions, running perhaps one or two hours per week for ten weeks. For these offerings, advanced registration and management approval of attendance was deemed necessary. The program was set up to be administered by the Corporate Staff Development Office but with the technical content controlled by the technical staff. All, or nearly all, of the sessions are scheduled during working hours and for those who are forced to miss a session we video tape and record as appropriate.

Before talking more about the nature of the program, let me indicate the kind of material offered. As you can see, in the attached table, the topics are very diverse. They deal not only with specific technical matters but with virtually any subject which could conceivably improve the effectiveness of our people in dealing with associate contractors or the customer or otherwise impact mission success. To illustrate the breadth of the program, we felt that a more intimate understanding of the on-site functions of government plant representatives would be useful to many of our program and support engineers, so we invited a DCAS representative in for an orientation talk. Likewise, the head of a local AFPRO group resident at a nearby associate came to speak with us. We try to address current problems and future technology, materials questions, testing, audits and inspection, future trends, etc. We are tapping the expertise of our own staff and that of our associate contractors and vendors who have been very cooperative in providing us speakers and material.

Since the PATP material has direct relationships with both our overall program support and identified problems, it has been possible to charge attendance at our sessions directly; that is, against program funds. Therefore, the separable costs of conducting the PATP have been minimal. To date, there have been well over 6,000 hours of attendance with perhaps 500 persons present at one or more sessions.

In contrast to conventional formal education, the program is intended to be extremely flexible and responsive to the needs of our staff. A particular session or series of sessions can be organized and held at the request of any group with legitimate need. Sessions can be easily repeated or tailored, schedules can be adjusted as required, many of the short sessions are held with minimum notice so that we can take advantage of specialists visiting the Los Angeles area for other reasons.

Management is encouraged to attend and promote the program within their organizations. Since our objective is not to make everyone a specialist in every topic, but rather increase awareness of key issues, it is appropriate that personnel at all levels in the Aerospace/SAMSO complex periodically attend.

Although it is always difficult to get an exact measure of the efficacy of educational programs, we have attempted by the use of questionnaires and monitoring of the sessions to determine the strengths and the improvable characteristics of the PATP. Responses on the questionnaires have been overwhelmingly positive and the vigor of discussion at most sessions also indicates a high level of interest in and utilization of the material being presented. These responses suggest a profitable return in terms of improved personnel effectiveness.

We recognized early-on the impracticality of adding enough manpower to our central product effectiveness support staff to cover all facets of each program. Our objective with the PATP is to make each manager and engineer who deals s with program elements a bit of a product assurance engineer himself--at least enough of one to spot a problem in the making and then call in a specialist. Initial results suggest the concept is working.

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Allan J. Boardman is the Director of the Sensors and Product Effectiveness Subdivision within the Electronics and Optics Division of The Aerospace Corporation. Within his subdivision are the Reliability and Statistics Department and the Components and Product Engineering Department, both of which provide engineering support services to all principal SAMSO programs. He has been with Aerospace since 1962. Prior to joining Aerospace Boardman was Assistant to the Vice President at Pickett, 1956-1959; Staff Project Engineer at Ramo-Wooldridge Corporation, 1959-1961. He received his bachelor's degree in aeronautical engineering from the Massachusetts Institute of Technology in 1955 and has taken graduate studies at University of Southern California and University of California at Los Angeles. He is a member of the Optical Society of America, and the American Institute of Aeronautics and Astronautics.

The Aerospace Corporation Product Assurance Training Program

Short Sessions	Extended Sessions
Static Awareness	Product Design
How to Succeed with an AFPRO	Package Design
	FMEA
Reliability & Components Data Center	Thick/Thin Film Technology
Gold-Aluminum Failure Mechanism	Optical Microscopy
	Failure Analysis
Tailoring of MIL-STD-1543	Basic Microcircuits
How and Why of Performing a Hardware Audit	Traveling Wave Tubes
	Preventing Vibration Failures
	Industry Ideas on Mission Assurance
	Thick Film Technology at DuPont
	Hybrid Memory for Voyager JPL)
	Hybrid Microelectronics Survey for Space and Missile Use
	Space Shuttle Users Symposium (Nationwide Teleconference)
	Defense Documentation Center
	Spacecraft Hydraulic and Pneumatic Integrity
	RTV Silicones
	DCAS Organization and Functions
	Military Specs & Standards
	VLSI Technology
	Integrating Engineering Disciplines
	High Reliability Semiconductors (Motorola)
	Microcircuit and Semiconductor Packaging
	Sneak Circuit Analysis

I. Additional Topics to be Covered as Part of the Product Assurance Training Program:

1. Inspection of Soldered Connections and Proper Soldering Techniques (Joyce Gardner)
2. Use of the Microscope for Quality Inspections (Jim Richardson)
3. Secondary Breakdown of Semiconductors (Mel Cohen)
4. Hybrid Microcircuit Packaging, Application and Testing (Don Fresh)
5. Program Application and Use of MIL-STD-1546(19) (Standardization and Control Program for the Selection, Application, Procurement and Management of Parts, Materials and Processes for Space, Launch and Re-Entry Systems)
6. Program Applications and Use of MIL-STD-1547(19) (Technical Requirements for Parts, Materials and Processes for Space, Launch and Re-Entry Systems)
7. Benefits of Coordinated Procurement and Line Surveillance

8. Use of LSI in Space, Launch and Re-Entry System

9. Dormancy Effects on Electronics for Space Systems

   NOTE: Numbers 4,5,6 and 8 are currently planned for extended sessions.

II. Recommend that contractors submit their ideas for subjects to be presented under the Aerospace/SAMSO Product Assurance Training Courses Program. The contractor can base his suggestions on what he could provide (speaker) or what he thinks would be of interest based on his experience.

THE SAMSO/AEROSPACE EXPERIENCE SHARING PROGRAM

Presented at the 1978 Industry/SAMSO Mission Assurance
Conference - Workshop
Los Angeles, California
26 April 1978

James M. Teresi

Key Words: Experience Sharing, Data Exchange, Data Bank, Data Center, SAMSO/Aerospace, GIDEP, Alert

Experience sharing....that is, information exchange... is a key element in any mission assurance endeavor. This has been recognized by the Industry and SAMSO executives who set up this conference and it has been emphasized in each of the keynote addresses of the conference. Indeed, there is a considerable degree of recognition among all of us in this business that there are various ways in which experience sharing can be accomplished and work to benefit our programs. These experience sharing methods range in scope and complexity from informal conversations between two individuals to highly organized conferences such as this and elaborate formal information exchange systems such as the Defense Documentation Center (DDC) and the Government Industry Data Exchange Program (GIDEP).

All forms of experience sharing have value and tend to aid the mission assurance effort. That's the overall message we want to convey in this portion of our Workshop. Because the DDC and GIDEP types of experience sharing systems are generally familiar to most of us, the limited time available for this presentation will be devoted to a specific application of experience sharing to the prupose of enhancing mission success for SAMSO programs. We call this effort the SAMSO/Aerospace Experience Sharing Program.

In the next few minutes, with the aid of a few graphic aids, I will acquaint you with this program, show its relationship to certain facets of GIDEP and seek to stimulate thought in your minds which will lead to fruitful discussion later today in the Workshop session.

Objectives of the SAMSO/Aerospace Experience Sharing Program are stated in Chart 2.

The principal functions involved in implementing the program and organizational responsibilities for their performance are shown in Chart 3. The planning and basic administration of the program are carried out by a small section within The Aerospace Corporation known as the Reliability and Components Data Center (RCDC).

The RCDC maintains four distinct data banks (see Chart 4). Two of these, the SAMSO/Aerospace Experience Retention Data Bank (ERDB) and the SAMSO/Aerospace Parts, Materials and Processes Usage Data Bank (PMP UDB) are unique to the SAMSO/Aerospace Experience Sharing Program.

The ERDB is a composite, computerized bank of data which integrates information generated in SAMSO programs with information obtained from various sources external to SAMSO programs. Additional details of the composition of this data bank will appear in the next chart.

The PMP UDB is a computerized bank of equipment parts, materials and processes lists for specific SAMSO programs. Having these PMP lists in the computer permits a rapid identification of programs which may be impacted by specific GIDEP Alerts or other conditions of immediate concern revealed by any of the various experience sharing media.

The ERDB and UDB are augmented by two of the microfilm data banks made available by GIDEP to Aerospace as one of its participating organizations. These are the GIDEP Engineering Data Bank (EDB) and the GIDEP Reliability and Maintainability Data Bank (R/MDB).

The left-hand side of Chart 5 shows the various types of documents which make up the SAMSO/Aerospace Experience Retention Data Bank. The right-hand side of this chart delineates the major types of routine and special outputs distributed by the RCDC, utilizing information retrieved from the data banks.

Charts 6.1 through 6.4 show the flow of the various types of information in the SAMSO/Aerospace/Industry experience sharing network.

Chart 6.1 shows the flow of information from SAMSO programs into the Aerospace Reliability and Components Data Center. Some of this data is received by the RCDC direct (as a contract CDRL addressee), but at present most of it is received indirectly via the cognizant SAMSO and/or Aerospace program office.

Chart 6.2 shows the flow of GIDEP Failure Experience Data Bank information (Alerts). Note here that the Aerospace RCDC serves as a central redistribution point of GIDEP Alerts to all Aerospace Corporation and SAMSO offices. In the case of SAMSO distribution, GIDEP Alerts are addressed by the RCDC to the Air Force Discrepant Parts and Components Control Program (DPCCP) monitors for each of the various System Program Offices (SPOs), as identified in a list supplied by the Directorate of Acquisition Support, Systems Effectiveness Branch (SAMSO/AWS).

Chart 6.3 shows the flow of GIDEP Engineering Data Bank information. Here again the Aerospace RCDC serves as the central point of receipt, repository and redistribution for Aerospace and SAMSO offices.

Chart 6.4 shows the flow of information from sources other than SAMSO programs and GIDEP into the Aerospace RCDC. Some of this information is received direct by the RCDC and some of it indirectly via SAMSO or other Aerospace offices.

The flow of output from the Aerospace RCDC is shown in Chart 6.5. Here it is seen that, at the present time, all distribution of RCDC-originated information to SAMSO program contractors is channeled through Aerospace and/or SAMSO offices. The feasibility and ramifications of direct distribution from the RCDC to contractors remains to be studied.

In Chart 7 we have cited a few of the problems that appear to confront us (in varying degrees of seriousness) in administering and effectively utilizing the SAMSO/Aerospace Experience Sharing Program. Although there is insufficient time available to discuss any of these in detail in the presentation, it is our hope that a meaningful exchange of ideas on at least some of them will take place in the workshop session which follows.

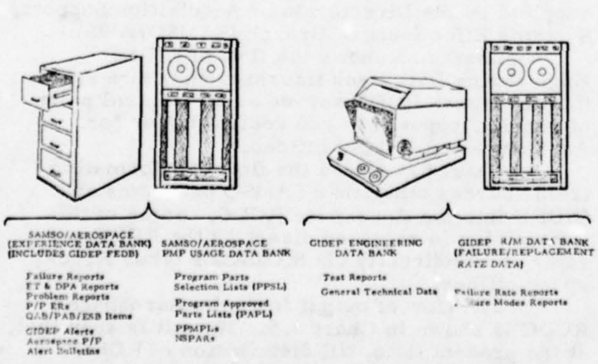
Program Objectives

- Acquire and permanently preserve technical and managerial experience information from SAMSO programs and available outside sources.
- Integrate SAMSO experience data with similar data from outside sources into a central, rapid-access data bank.
- Provide data retrieval and dissemination services which effectively facilitate and encourage application of past experience information to enhance mission assurance for current and future SAMSO programs.

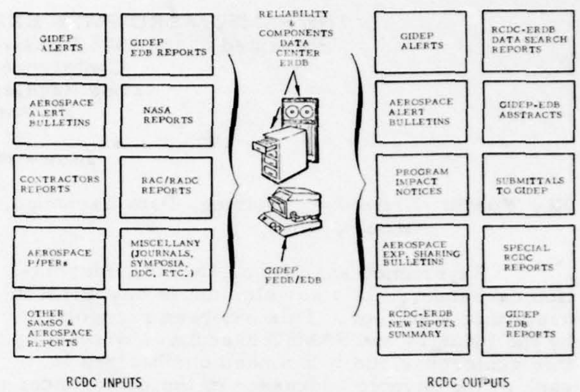
PROGRAM FUNCTIONS & RESPONSIBILITIES

FUNCTION	RESPONSIBILITY: SAMSO CONTRACTORS — POs & SUPPORT OFFICES	SAMSO — SPOs & SUPPORT OFFICES	AEROSPACE — RPOs & SUPPORT OFFICES	AEROSPACE — RCDC
DATA ACQUISITION & REPORTING	X	X	X	
DATA INTEGRATION & BANKING				X
DATA RETRIEVAL & DISSEMINATION				X
DATA UTILIZATION	X	X	X	

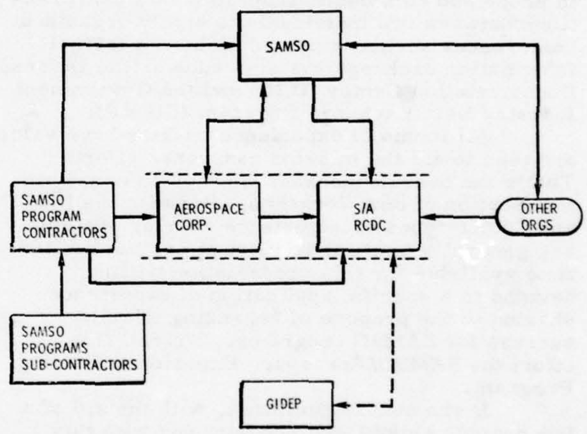
THE RCDC DATA BANKS



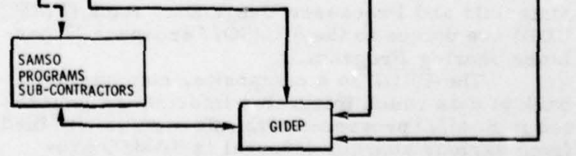
EXPERIENCE SHARING MEDIA



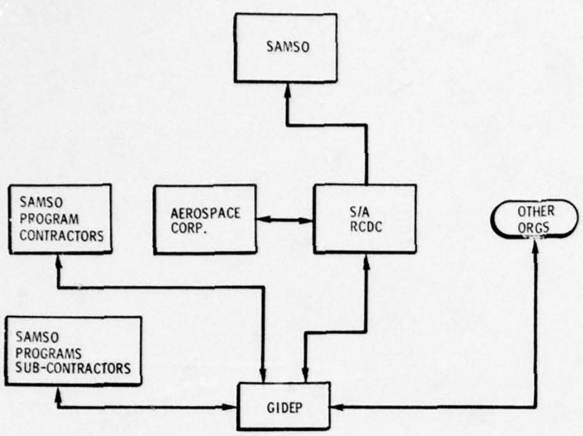
SAMSO PROGRAMS INPUT



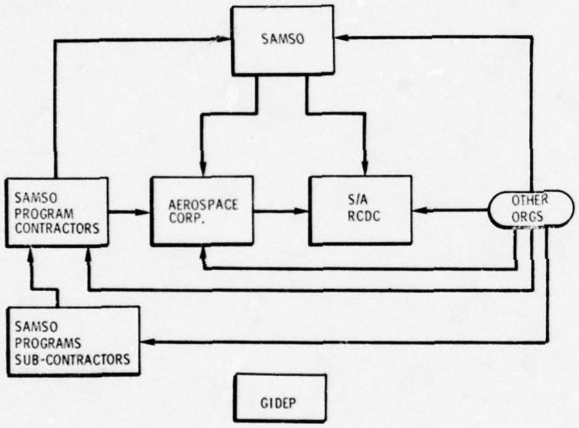
GIDEP FEDB DATA



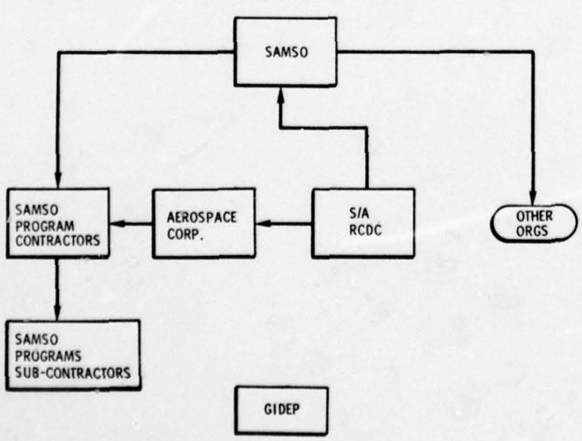
GIDEP EDB DATA



NON-SAMSO/NON-GIDEP DATA



INTEGRATED ERDB OUTPUT



Problem Areas

- Product/Process Identification

  Multiple P/Ns, nomenclature, variations of basic type

- Information Integrity

  Accuracy, objectivity, completeness, timeliness

- Information Significance Appraisal

  Criticality rating, scope of impact, usefulness

- Closing the Loop

  Action definition, assignment, motivation, follow-up, data bank up-date/purge

- Distribution Lists

  Establishing, maintaining.

WORKSHOP SUMMARY

WORKSHOP I

INDUSTRY'S APPROACH TO PERSONNEL MOTIVATION AND TRAINING AND SAMSO/AEROSPACE/ INDUSTRY EXPERIENCE SHARING DISCUSSION GROUP SUMMARIES

I. QC Circles and Related Programs

- QC circles have been tried with some successes
  - Raise job satisfaction, morale, productivity, etc.
- Techniques relatively new in American industry

therefore:

- Expose other organizations in the SAMSO community to techniques, successes, problems, benefits
  - Publish experiences, guidelines, case studies
  - Hold seminars for inter-company sharing at working level

ACTION: Industry - individual initiative

- Organizational - specialty groups

II. In-Plant Motivators - Use of Techniques from the Behavioral Sciences

- Many managers from "old school" uninformed about effective techniques or reluctant to use them
- Studies indicate needs - e.g., grossly differing perceptions of people, job, goals as function of organizational level

therefore:

- Provide greater exposure of methods to management
- Train customer personnel on impact of interactions with contractor (example: gen. nuts and bolts)

ACTION: Industry, government, professional societies

Also consider:

- Motivation is not something we "do to people" - rather create the right environment to enable generators to operate
- Minimize the extent to which checking other people's work is necessary - operator accountability
- Develop self-sustaining techniques

IIIA. Experience Sharing

- Common perception of the benefits of a good experience sharing system
- Simply not enough interest anywhere in systematic improvement in experience sharing; not set up organizationally to do a better job
- List of deterrents extensive -
  - Fear of embarrassment
  - Too much trouble to input
  - Proprietary info
  - Legal questions
  - etc.

therefore:

- Must examine list of deterrents, overcome or override with contractual requirements and/or incentives

ACTION: SAMSO/AEROSPACE Task Force to review and propose specific recommendations

IIIB. Training

- No major industry problems identified in "operator" training
- Challenge to industry to apply modern technology (computer aids, e.g.) to streamline training
- Government and industry both need some form of training programs to pass along expertise in RFP and proposal preparation, requirements translations, etc.

IV. Customer Involvement and Organizational Influences on Motivation

- Little SAMSO recognition of value of motivational programs
- Motivational programs seldom directly funded

therefore:

- RFP's should encourage motivational programs as a line item where ROI can be demonstrated
- SAMSO should employ motivational programs in their own organizations - lead the way
- SAMSO should encourage contractors to recognize their outstanding performers/groups
- SAMSO should prepare and distribute list of lessons learned

ACTION: SAMSO

Also consider:

- SAMSO publicity of successful contractor efforts with care
- SAMSO/industry working group and/or bulletin to investigate and serve motivation

  Training

  Experience sharing

Highlights from Paper Presentations Personnel Motivation, Training and Experience Sharing

Motivation

- Motivation comes from within
- Put time limit on program or modify periodically
- Use formal organization
- Major benefits from QC circles, peps, team
  - Supervisory training
  - Teaching people how to define problems and develop solutions
  - Communications
  - Job enrichment
  - Between 4:1 to 9:1 cost-benefit ratio
- Involve all levels of management
- Suggestion systems versus employee meetings
- Consider more group incentive programs
- Restructure jobs to include planning, scheduling, controlling, innovating
- Certify manufacturers to perform own inspection

Training

- Technical personnel inter-disciplinary training accomplished by short on-the-job courses. Related to work.
- Variable government certification programs

Experience Sharing

- Large payoff from technical and management data banks

CLOSING REMARKS

Dr. Albert D. Wheelon, Hughes

Mr. T. A. Meaker, European Space Research Organization

Mr. Gerald E. Lutz, Fairchild Space and Electronics Company

MISSION ASSURANCE CONFERENCE
NSIA SPONSORED – INDUSTRY/SAMSO

27 April 1978

Closing Address by: Albert D. Wheelon

After three days on the subject of mission assurance, I expect you have heard just about everything that can be said on the subject. It is not easy for me to say something new. I will comment on a few of the more important items raised in this conference, and will add a few perspectives of my own.

First, let me say that industry is in good shape today. It can be better, but it has been lots worse. I recall ballistic missiles in 1957 and 1958 – 20 years ago, when every attempt to launch was an adventure, and most of our products ended up in the water. I remember the start of Intelsat IV 10 years ago. At that time, $30M of the $100M revenue was riding on orbital performance. We needed to get 5 years successful performance in orbit to cover our costs. The first Intelsat IV bird is now 7.3 years old. Today, we are all building and performing to higher standards. This change is the result of the efforts of people in this room who have made steady progress each year.

The question is: How do we progress from here? That was the purpose of this conference. I remarked to Tom Morgan a year ago that such meetings – held under Air Force auspices – are difficult for industry to hold by itself in view of antitrust laws. This conference is valuable and should be repeated regularly. But it is not an end in itself.

I would like to ask: How many people in this room will do "hands-on" labor on space hardware this year? I will not. How many will design and make drawings for space hardware this year? I will not. The answer to both questions is "Not too many." The fact is that the destiny of spacecraft is in the hands of people outside this room.

We in the room are like the clergy in the early Christian churches. We can teach; we can exhort; we can encourage – but we cannot do the work of the world. Only by enlightened evangelism can we excite those who will do it – to do so superbly well. If, like the medieval clergy, we occupy ourselves with the refinements of dogma, we will have failed in our primary purpose.

How do we reward and encourage people for working hard to provide Mission Assurance – real spacecraft operating flawlessly in orbit? I believe the answer is "Not very well." We have the stick but not the carrot.

A common misperception by Government is that industry is motivated solely by profit. Certainly, the individual engineer who directly affects mission assurance is far removed from the influence of profit. So it is the management we are talking about. The view of modern management is far broader than corporate profits. Continuity and dignity of employment are high on the list of corporate goals. That is why George Meany is opposed to licensing U.S. products to foreign firms who then destroy the firms and the jobs that created those products by predatory pricing. The profits that come from those licensing arrangements in no way compensate people for the suffering of unemployment created thereby. As a further example, 1976 and 1977 were the most profitable years in the history of my part of the Hughes Aircraft Company. But for me they were the most painful because we had to lay off 1000 of our 5000 people. I believe that the Government does not yet recognize the broader motivation of modern industrial management. When it does, it will recognize that the present incentives for mission assurance are at least inadequate and sometimes counterproductive.

Well, what does counterproductive mean? It means that if we build a 10 year spacecraft rather than a 5 year spacecraft, we will get exactly half as many orders. That means half as many jobs. The cruel consequence of maintaining operating systems in space is that a short orbital life means more sales – and hence more jobs. You say that will eventually catch up with the less reliable supplier But does it? Do we have a mechanism, sanctioned by ASPR, which allows the government to recognize the superior performance of one spacecraft supplier vs. another? Can the government refer in any meaningful way to prior performance in orbit when making source selection decisions? You and I do this in buying a TV set or a car. But I submit that the Government has not yet found a way to recognize performance; in contrast to liturgical discipline of formal product assurance plans.

We all see the coming of Shuttle as a new day in space, providing new directions for design and test. But the other side of the coin is the wind-down of Thor Delta, Atlas Centaur, and Titan. How do we motivate those people who will soon be looking for new jobs, especially since we still have a lot of satellites to fly with those rockets?

This conference has discussed the desirability of focusing space business on a few electronic components that will ensure the reliability we need.

I believe this is important especially in view of the terrific diversion of integrated circuit manufacturers to the commercial market. But such focusing has already taken place in ways that many of us do not recognize.

For instance, I believe that everyone in the industry buys titanium tubing from a single supplier; we are critically dependent on his quality standards, which have their ups and downs. I believe that everyone buys nickel-cadmium batteries from one supplier, whose primary emphasis is building batteries for golf carts and fork lift trucks. It is no secret that some battery lots are better than others.

Consequently, I am making two main points: The first is that there is a surprising amount of focusing – the pyramid standing on its tip – and that we all depend on the performance of a few people, who have periodic shortfalls. The second is that the problem is broader than electronic parts. We judge that half our orbital problems are mechanical and half are electronic. We must keep a balanced view of our liabilities.

We are trying to enhance Mission Assurance within fixed economic boundaries. I like very much General Low's term "Affordable mission assurance." That is the reality of our situation. Whether we be on firm fixed price or cost plus contract, there

is a limit to the amount of money available for Mission Assurance. And it seems it is never enough. Certainly it is not enough to nail every question down firmly. Whether we like it or not, there continues to be an element of chance in our business. The problem is to know the odds and weigh them in our favor. And to know how much is enough!

Mission Assurance must be woven into the fabric of program management. It cannot afford to be a thing apart. We employ a system at Hughes that helps this weaving. We devote each Friday to an in-depth review of our ten major spacecraft programs. I chair that meeting and our Product Assurance people participate. They are expected to provide an independent view on how things are going in each program. They do so. It is a healthy system which seeks to surface problems and uncertainties while the spacecraft are still here on earth and we can fix them. The program managers have come to regard this as a forum in which they can get management support for all their problems. I believe it provides a healthy forum for integrating mission assurance into the lifeblood of our activities. I gather that other companies use essentially the same technique.

This conference is the first attempt to examine all the influences that affect Mission Assurance. It has covered design, manufacturing, quality assurance, testing, subcontractor management, software management, contractual incentives, and human motivation. It is possibly a turning point in the conduct of our business. It is important that the concept developed here should not be dropped and that effective follow-up be maintained.

We owe a considerable debt to General Morgan, who was the principal force behind this meeting. I would like to add my best wishes to those of others as General Morgan leaves SAMSO and a valuable legacy to us all.

Comments by Mr. T.A. Meaker

Head of Product Assurance, Telecommunication Satellites Department EUROPEAN SPACE AGENCY – Netherlands

Mr. Chairman, Ladies and Gentlemen:

In being asked to give a summary overview of the conference I feel rather like a Freshman being asked to comment at a Graduation ceremony. Nevertheless I would like to make a few observations and perhaps I may begin by making a few comments about the European space efforts.

As the chairman has indicated I work for the European Space Agency which is roughly the European equivalent of NASA. I am therefore essentially a member of a Government's Organization i.e. the customer, and interface frequently with contractors and sub-contractors etc. At the moment the main efforts at ESA are devoted to the Telecommunication Satellite Programmes, Spacelab for Shuttle Applications and Scientific Satellites. I am a member of the Telecommunication Satellites Department headed up by Dr. R. Collette and at the moment we are involved in Maritime, Indirect and Direct Television Broadcasting and Telecon service satellites.

ESA also has an extensive ground based communications network and is involved in a fair amount of basic research activity.

I would like to mention that the major consortia in Europe have worked with a number of American space organizations and thus you can share in the successes we have had in our space programmes.

I believe the Workshop form of this conference has enabled an eyeball to eyeball exchange of ideas, criticisms and suggestions in rather critical areas. The structuring of the workshops has clearly been very carefully thought out and the control of the rather complicated committee sessions has been extremely well handled.

A characteristic of the conference that has been apparent to myself is that realistic, pragmatic discussion has taken place. There has been some extremely hard, blunt argument and controversies have been discussed, without animosity. What is probably more important, with the many service members present, is that there has been no "pulling of rank" to win a point in debate.

A conference of this description is rather unique. The conference has been convened by Government and a very wide selection of industrial engineers has attended. With such representation, on both sides as it were, I think a redeeming feature of the conference has been that most of the people concerned have ADMITTED problems and inadequacies. Additionally, limitations have been recognized and advice has been accepted. Amidst all this ammunition for dissent, humor and mutual respect have been maintained. I am also very pleased to have noted that no "sacred cows" have been acknowledged.

It seems to me that we are constantly re-inventing the wheel. The reason for this, in many cases, is that there is inadequate communication and too much customer-contractor class distinction. This sort of conference will hopefully reduce the re-invention process by recording the non-text-book

process by recording the non-text-book aspects of our business.

If you will bear with me for a few moments I would like to make a few points in which I am particularly interested.

We are constantly and continuously being penalized for our failure to quantitatively define the mission early in programme. Commensurate with this comment I would like to make the observation that although the customer invariably makes the policy, this policy, whether we like it or not, is only defined by the specifications. Now, as we all know, specifications do change and we should realize that with the changes in the specifications so our policies are also changing. In many cases there is a very tenuous connection between the final specifications and the policy makers. Perhaps some sort of mechanism should be established which, from time to time, analyses the specifications to determine precisely what the changes in the policy are.

I find the title and the mixed discipline content, of this conference very satisfying. In the space business with so many disciplines and skills DEPENDENTLY involved, it is clear that no single type of expertise is more important than another.

Hence the elimination of the second class citizen concept for product assurance engineers, contract officers, finance people, sheet metal workers etc. is fundamentally important. I believe that the design engineer is not a supreme, isolated, sacrosanct paragon and the quicker the integrated concept of our work and our people is implemented the more successful our missions will become.

We are living in an age of inventiveness, innovation and initiative with the predictable result of exotic technologies and custom designs. As mentioned at this conference the promulgation, in this diverse environment, of AGREED standardization in specifications etc. is tremendously important. The standardization will to a certain extent restrict the use of new products but, in the long run, I believe this will lead to higher assurance of mission success.

In our business I am becoming increasingly aware of the interface problems that are besetting our programmes. In this respect, and this has been emphasized in one or two of the workshops, the importance of CADM and technical interface management cannot be overestimated. In the context of this remark I would like to mention the difficulties we are currently having in defining the shuttle payload interfaces from the information currently available.

I would like to say a few words about WORKMANSHIP. Workmanship has been extensively discussed at this conference, both in absolute terms and in the transition process from design to hardware manufacture. A number of speakers have passed comment about the number of PH.D's* in a particular committe and have drawn the conclusion that the committee result would therefore be a good one because of the "large amount of brainpower present." I naturally recognize the importance of PH.D's and without their very specialist research knowledge many of our

*Doctor of Philosophy

problems would remain unsolved. I do, however think that there is a very big imbalance between workmanship skills/industrial engineering and the PH.D. Perhaps we should recognize a concept of "PH.D in workmanship/experience." The implementation of this concept may in fact be more effective in reducing the final 10% of defects we are currently looking for. The previous speaker made some extremely perceptive comments about motivation and continuation of hardware standards; I would like to say that I fully endorse his observation.

Perhaps on the government/customer side and bearing in mind the difficult financial/budget climate, I would like to make a brief comment on payments. Some speakers have said "you get what you pay for." I believe we should also remember that you often "get what you do <u>not</u> pay for" and this can be the "FAILURES." This comment, of course, applies not only to government/customer but also to main contractors when subcontracting to lower tier contractors.

As a concluding comment, I believe this conference has been very successful, but the ultimate success depends on the continuing close relationship and integration of government (customer) and industry. Initiative, as shown in convening this conference, will always pay; complacency, from now on, is the enemy. The customer and the contractor must <u>recognize</u> and <u>use</u> each others <u>contributions</u> and <u>limitations.</u>

I would like to congratulate the organizers of this conference in producing such a co-ordinated and current event. The conference is as much the people who attend and the contributions they have made have been invaluable. I thank you for the opportunity to attend and would welcome you to visit ESA if you are in Europe.

Gerald E. Lutz

Director of Quality Assurance
Fairchild Space and Electronics Company

I have been most impressed with the vast array of recommendations that have been developed and presented during this workshop. Not only are the workshop coordinators to be complimented on a thorough summarization, but each of you deserve plaudits for your forthright comments and suggestions.

If this symposium is to be considered a success, then positive and constructive change must be evolved as a result of the many comments provided. It is our intent to continue to support SAMSO in the development of specific actions to the degree they desire.

Towards that objective then, papers and workshop summaries will be published to serve as the source material. We view this workshop as but another step in a continuing effort to enhance Mission Assurance.

The ultimate measure of success will be space performance in the future that meets or exceeds mission performance requirements to a greater degree than in the past. This is especially challenging as mission durations will extend and mission complexity is increased. That this can be done, I have no doubts. How well we utilized this open forum to achieve these results will be the yardstick of our success.

I would like to assure SAMSO and Aerospace that Industry stands ready to support the implementation of the resulting recommendations in whatever manner may be appropriate – whether this be special task forces, additional workshops, special evaluations or whatever appears warranted.

Our objectives parallel yours – improve Mission Assurance and improve costs.

It would take the rest of the day to acknowledge the many people whose dedication and perseverance made this conference successful, however, I will take the opportunity to reflect on them collectively:

- Industry Program Committee
- SAMSO/Aerospace Program Committee
- Ad Hoc Committee
- Workshop Co-Chairmen
- Workshop Co-ordinators
- Discussion Moderators
- Speakers
- Panelists
- NSIA Staff
- Administrative Personnel
- Each of you as a contributor

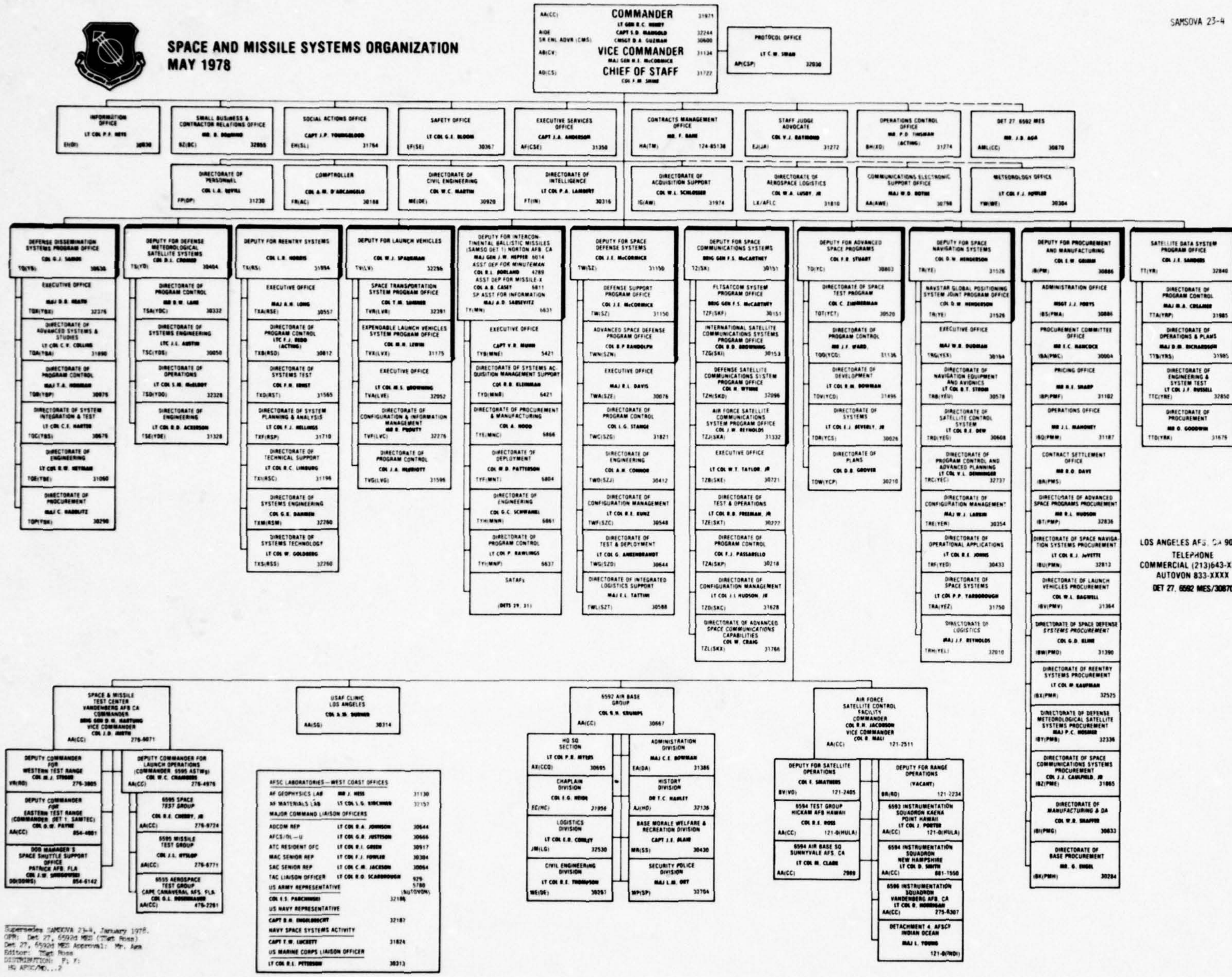
Last, but certainly not least, those who assisted with registration, message center, and worked late into the night making Vue-Graphs and supporting these reviews. Thank you again for making this workshop productive.

If there are any questions, I will try to answer them. If not, the meeting is adjourned.

APPENDIX A
SAMSO ORGANIZATION

SAMSOVA 23-4

SPACE AND MISSILE SYSTEMS ORGANIZATION
MAY 1978



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APPENDIX B
SUMMARY OF SAMSO/INDUSTRY EXECUTIVE SESSIONS

22 June 1977
7 July 1977
20 July 1977

Opening Remarks

The items discussed at the meetings were suggested by the contractors. Although the subjects were similar at each meeting, the emphasis and relative importance placed on the discussion varied among the meetings. In opening the meetings, General Morgan pointed out that while the record of spacecraft success is very good, the impact of a small number of space failures can have an exceptionally adverse effect. This impact goes beyond the initial operational loss and the staggering loss of resources at many levels. The ability to obtain Congressional support for future budget allocations is seriously impeded. Management at all levels must recognize that for space applications, we must strive to achieve perfection. At times this may be initially costly; however, the alternative of failure is even more costly.

Incentives

Achieving the appropriate balance of contract incentives is considered very important in motivating contractor management in the right direction. Several examples of how incentives can actually contribute to failures, anomalies and performance degradation were given. For example, schedule incentives with a fixed price contract, when technical problems are encountered, could encourage short cuts. Unrealistic estimates of cost and schedule often result in decisions have an adverse effect on mission performance. Timing of incentive payments is also important to maximize the motivation desired.

Performance oriented incentives significantly greater than cost or schedule are considered a strong tool for focusing management attention on those areas that enhance the probability of mission success. Properly drawn, incentives could be the guide for every management decision and tradeoff in deciding how and where to apply resources. The following are additional ideas, comments and suggestions concerning incentives discussed at the meeting.

- Some attendees felt that multi-year on-orbit performance incentives that are paid downstream are not effective. The performance of contractor personnel is graded in the present, not in the future.
- Early payment of incentives when initial performance is achieved is effective. We might consider the use of incentives in the front end of the program and assess penalties if full performance is not attained.
- Award fees, properly structured and operated, are a good management tool. Both parties should have commonality of purpose and mutual understanding of the award fee plan.
- Contract incentives can be used by management to motivate personnel to avoid practices that might inadvertently degrade the product. Incentives should be passed down to the first line supervisors or lower in "real time."
- Both parties should have a clear understanding of the incentive structure before starting work. Rules should be published in advance. Also, there should be no conflict between incentives, i.e., cost schedule vs performance.

Motivation

There was a general feeling that one of the most important attributes of mission assurance is motivation of the work force and instilling an awareness of the importance and criticality of spacecraft hardware. Several contractors have implemented formal programs for this purpose. It was pointed out, however, that formal programs often lose their vigor after a period of time and must be constantly updated. It was felt that to be effective, motivational programs must have complete support of top management. The motivational process must also "flow down" to the subcontractors and vendors. Techniques described included cash awards, expense paid trips to witness launches, movies, participation of AF personnel and presentations on how the products and people contribute to the space program. Many felt it is essential to instill in all employees a personal feeling of responsibility and a feeling of involvement. The motivation process also involves a sharing of successes with personnel involved.

The subject of personnel motivation could be closely associated with contract incentives. Using the incentive resources to reward personal performance, and getting it passed on to the man or woman on the bench, is a very important aspect of mission assurance.

Contractor/Government Relations

On the subject of contractor/Government relationship, the discussion centered about the degree of Government engagement vs disengagement. It was acknowledged that the DOD climate and policy in this area were subject to change from time to time and, therefore, establishing an appropriate balance between the two extremes is a matter of experience and sound judgment. The two extremes might be characterized by a concept similar to the total package procurement on one hand, and on the other hand an "engagement" activity that sees the Government making contractors' decisions and performing contractor tasks.

The general opinion was that openness on both sides was a desirable arrangement, if the arrangement is businesslike. Conversely, an "adversary" approach should be avoided.

Many factors influenced the proper engagement/disengagement balance, such as the stage of development, risks involved, type of contract, state-of-the-art, etc. One point brought up during these discussions was the importance of attaining complete understanding between the Government and contractor personnel concerning all aspects of newly awarded contracts. It was noted that often, during the source selection and negotiating phase, personnel on both sides are not the same personnel as those who may eventually manage the contract. The need for postaward reviews was stressed to make sure both Government and industry start with a firm

understanding of the contract requirements and tailored application of specifications and standards. This postaward review should include those functional management and contractual areas in which misunderstandings are most likely to occur.

Type of Contract

With the DOD emphasis on fixed price contracts, the discussion centered on whether or not the type of contract for fabrication of hardware could affect performance. Primarily, the question was: Does a fixed price environment lead the contractor's work force to make decisions, i.e., take shortcuts that inadvertently contribute to performance degradation, or fail to surface latent defects that later result in failures or anomalies.

As might be expected, the opinion was divided on this question. The question is complex and many factors are involved, such as the stability of design, producibility of the design, schedule, incentive structure, and validity of the cost estimate. It was felt that when risks are high, a cost-plus arrangement is appropriate but steps must be taken to minimize "buying in."

While it was generally agreed that it was not wise for industry to gamble on the unknowns, it was noted that some companies have had favorable experience with fixed price contracts in the commercial satellite business, particularly when most risks are known.

During this discussion, a point was made that mission success and successful programs often tend to lead SAMSO to believe that costs can then be reduced. Some participants felt that attempting to reduce costs on successful programs may cause degradation to the successful team and might lead to future problems.

Design

One of the factors affecting the design of modern military spacecraft is that of increasing complexity. This is caused in part by the increasing number of functions a spacecraft is required to perform. Often the concept of operations becomes overly optimistic, resulting in various agencies adding on functions and capabilities. The resulting increase in complexity and parts count has a "snowball" effect on the entire process from design through launch. While there is no single most important factor to consider in the design phase, it was felt that the design sets the stage for mission success. The following are highlights of various practices and ideas suggested.

- Achievement of mission success should be made a primary design goal. During the early design phase, a complete assessment of all risks should be accomplished to make sure the approach is realistic. The general feeling was that overly optimistic design approaches often result in "building in" latent defects.

- The point was made that the desire to achieve the maximum capability and spacecraft performance could result in "over specification." The effort to achieve this last percent of performance may often be costly and counterproductive.

- The Failure Modes and Effects Analysis (FMEA) was considered an important tool for structuring the design process. The FMEA should be integrated into design trade-off studies to make sure potential single point failures are controlled. The FMEA is also a good basis for establishing inspection, test, and critical process requirements for monitoring during fabrication. Many attendees stressed the importance of keeping the FMEA updated whenever any design changes are made.

- The use of redundancy was considered to be a good approach for control of potential single point failures. However, it was pointed out that redundancy should not be used as a crutch for weak design solutions.

- Several attendees stated that requiring an independent assessment of the spacecraft design was a useful approach to assure that as many potential problems as possible are eliminated at the outset.

- The importance of not leaving design problems to be resolved during manufacture was stressed. It was noted that this problem can be mitigated by requiring manufacturing and quality assurance "sign off" on the design prior to release to production.

- There was a discussion concerning the necessity or desirability of including features to accommodate repair, replacement and maintenance in spacecraft design. It has been generally believed in the past that such requirements were not required for space applications. However, many instances were pointed out where repair or replacement of parts were required before launch and such features would have been helpful. It was also noted that whenever long-term storage of spacecraft was contemplated, design features to accommodate repair should be considered.

Testing

Most attendees felt that thorough and extensive testing of parts, components and subsystems should be planned and adequately scheduled from the outset. Adequate testing at lower levels of assembly, at proper environmental parameters, reduces problems at system level tests and avoids overall schedule impact by reducing rework and retest.

A strong case was made for exercise of the equipment in the same manner as it is expected to be operated on-orbit, including all redundant paths, backup modes, and the exercising of on-board fault detection circuitry. Monitor functions continuously so that transients that might be indicative of latent problems are not missed. Including anomaly simulation into the testing techniques is also considered to have merit. It is especially important the program schedule provide adequate time for testing at all levels of assembly.

It was considered very important to accomplish a thorough analysis of test data to assure potential failures and latent defects are identified and ferreted out. Experience has also shown that identifying and replacing marginal parts at lower levels

of assembly decreases costs significantly in downstream activity. In the same vein, the root cause of all failures and anomalies encountered during testing must be identified and corrected.

Reviews and Audits

Many contractors have established separate "mission success" organizations apart from the classical functional organizations. Such organizations not only perform technical audits, they serve as a moving force for motivation and discipline to assure all appropriate actions are taken and mission success visibility is retained at a higher level. However, it was pointed out that caution must be exercised to avoid committee action from replacing individual motivation and responsibility.

Purchased Electronic Piece Parts

It was generally agreed that obtaining reliable piece parts is a continuing problem for the space industry. The primary cause appears to be the small quantity purchased by individual contractors, and therefore, vendors are reluctant to initiate unprofitable processes and controls.

Stringent measures and control of piece part vendors and subcontractors are essential to obtain reliable parts. Increased source inspection and monitoring of the vendors' processes are necessary to minimize problems. Rigorous testing, analysis of samples, and special screening inspections are essential. Monitored production lines for microelectronic piece parts indicates that significantly improved reliability can be achieved.

The importance of proper screening and elimination of marginal parts is essential to preclude the introduction of new problems when faulty parts are "changed out" during production.

At SAMSO, the Commander has established a "Select Committee on Piece Parts" to study all aspects of this problem. The committee is considering several alternatives and changes to standard ways of doing business for this aspect of program management. This committee has and will continue to interface with SAMSO contractors to exchange information on piece part reliability.

Manufacturing and Quality Assurance

It was felt that low volume, high reliability spacecraft and booster programs present unique problems. Experienced high-caliber technicians must be used for fabrication and test, and often it is difficult to maintain continuity of an experienced team. The transition from design to fabrication requires more attention to work instructions to assure the inherent quality is not degraded during manufacture.

Inspection planning and inspectability should be given careful consideration during design and planning phases. Relating the Failure Mode and Effects Analysis (FMEA) to the methods of manufacturing, assembly, inspection and test that will be employed for the various elements of a system is essential.

Quality assurance personnel need to accept the challenge of extending their role beyond "conformance" to that of improving the design and processes. Also, in-depth analysis of defects and discrepancies, to identify and correct root causes, is essential for mitigation of latent defects.

Some attendees indicated that quality assurance and configuration control of software is becoming increasingly important. Because of the increasing complexity of spacecraft, testing is being automated at a rapid pace. It is important that the nondeliverable software be subjected to the same controls and discipline as deliverable software and hardware.

Experience Sharing/Communications

Many attendees expressed the need for a more effective means of sharing experience, both among contractors and between the contractors and SAMSO/Aerospace. Experience sharing, it was felt, should include both success information as well as adverse experiences in the form of "lessons learned." Industry guests expressed their appreciation for the opportunity to meet with the SAMSO Commander and their industry counterparts. Other specific suggestions included:

- Holding similar meetings periodically.
- Having broader base meetings at program manager and functional speciality level.
- A better means of informing contractors of the SAMSO experience with their equipment should be explored.
- Flight failure and anomaly information should be passed on to all contractors affected.
- The use of ALERTS should be studied with the view of providing more useful information to contractors.
- We might look into the airline industry's method of disseminating problem information.

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APPENDIX C

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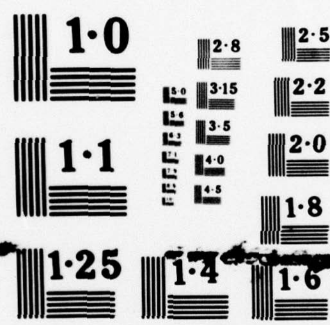

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